

AD-A142 890

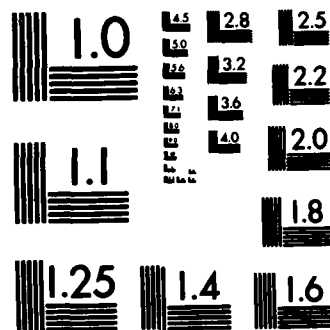
GRAND RIVER BASIN BOWMAN - HALEY DAM AND LAKE NORTH
DAKOTA SEISMIC EVALUATION AND ANALYSIS(U) CORPS OF
ENGINEERS OMAHA NE SEP 83

1/1

UNCLASSIFIED

F/G 13/13

NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

RECONNAISSANCE REPORT

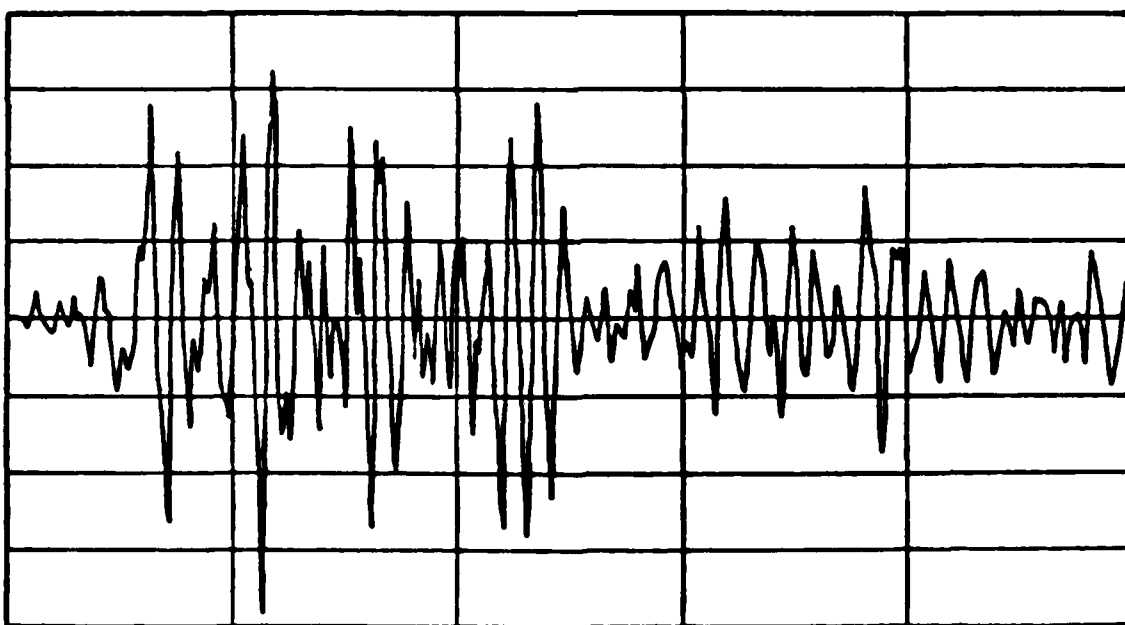
September 1983

③

AD-A142 890

Grand River Basin
BOWMAN - HALEY DAM AND LAKE
North Dakota

SEISMIC EVALUATION AND ANALYSIS



HTP FILE COPY



US Army Corps
of Engineers
Omaha District

DTIC
ELECTE
JUL 1 0 1984
S E D

84 07 05 089

GRAND RIVER BASIN - HALEY, NORTH DAKOTA

BOWMAN-HALEY DAM AND LAKE

RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS



Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	<i>form 50 per</i>
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

SEPTEMBER 1983

U.S. ARMY ENGINEER DISTRICT, OMAHA

"Original contains color plates: All DTIC reproductions will be in black and white"

**GRAND RIVER BASIN - HALEY, NORTH DAKOTA
BOHMAN-HALEY DAM AND LAKE**

**RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS**

TABLE OF CONTENTS

<u>PARAGRAPH</u>	<u>TITLE</u>	<u>PAGE NO.</u>
1.	PURPOSE AND SCOPE	1
2.	PROJECT LOCATION AND DESCRIPTION	1
3.	SEISMIC EVALUATION CRITERIA	2
3.1	Seismic Hazard Analysis	2
3.2	Postulated Earthquake	2
4.	EMBANKMENT	2
4.1	Embankment Features	2
4.2	Compaction Equipment	3
4.3	Embankment Materials	4
4.4	Material Placement and Compaction	5
4.5	Evaluation of Embankment Liquefaction Potential	6
5.	FOUNDATION	7
5.1	Foundation Explorations	7
5.2	Foundation Conditions	7
5.3	Foundation Design	8
6.	PROPOSED WORK TO COMPLETE SEISMIC EVALUATION	8
6.1	Field Investigation	8
6.2	Laboratory Analysis	8
6.3	Evaluation of Data to Determine Foundation Liquefaction Potential	9
6.4	Cost Estimate	10
7.	RECOMMENDATION	10

<u>TABLE</u>	<u>TITLE</u>	
1	Compaction Equipment Used in Construction	3
2	Specified Compaction Procedures - Embankment Fill	5

<u>PLATE</u>	<u>TITLE</u>
1	Location Map, Vicinity Map, and Embankment Sections
2	Seismotectonic Provinces and Seismicity Map
3	Embankment Plan with Original and Proposed Seismic Evaluation Foundation Explorations (sheet 1 of 2)

PLATE

TITLE

- | | |
|---|---|
| 4 | Embankment Plan with Original and Proposed Foundation
Explorations (sheet 2 of 2) |
| 5 | Embankment Sections 1-1, 2-2, and 3-3 |
| 6 | Geologic Profile Along Embankment C/L, Section 4-4 |
| 7 | Geologic Sections 5-5 thru 8-8 with Original and
Proposed Seismic Evaluation Foundation Explorations |
| 8 | Geologic Sections 9-9 thru 12-12 with Original and
Proposed Foundation Explorations |

APPENDIX A

Preliminary Seismic Hazard Analysis

APPENDIX B

Detailed Descriptions - Earthquakes in
North Dakota and Adjacent States

**RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS**

**GRAND RIVER BASIN - HALEY, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE**

1. **PURPOSE AND SCOPE.** The Omaha District in accordance with Engineering Regulation (ER) 1110-2-1806, "Earthwork Design and Analysis for Corps of Engineers Dams," dated 16 May 1983, is required to conduct detailed seismic evaluations of selected earthdams on sand foundations. The purpose of this Reconnaissance Report, prepared in accordance with appendix A of ER 1130-2-417 "Major Rehabilitation Program and Dam Safety Assurance Program," dated 30 November 1980, is to present a summary of available data necessary to determine the need for such an analysis. The scope of the report includes (1) a summary of preconstruction and construction data; (2) a preliminary seismic risk analysis; (3) an evaluation of the embankment materials ability to resist postulated earthquake shaking without detrimental effects; and (4) a summary of work required to complete the seismic evaluation of the site.

2. **PROJECT LOCATION AND DESCRIPTION.** Bowman-Haley Dam is located on the North Fork of Grand River in Bowman County, North Dakota. This location is about 6 miles upstream from the town of Haley, North Dakota and just downstream of the confluence with Spring Creek, a left bank tributary of the North Fork. The project controls runoff from 471 square miles. The dam is a rolled earth fill embankment, 79 feet high above the channel bottom and 5,730 feet long. The crest is at elevation 2794 and is 25 feet wide. An uncontrolled earthen cut and grassed emergency spillway is located in the right abutment. The spillway contains a soil cement scour cutoff and a fuse plug. The soil cement scour cutoff was provided to halt erosion of the spillway floor during periods of flow, and the fuse plug was designed to store 90 percent of the standard project flood but to fail when overtopped by floods of greater magnitude. The outlet works consists of a two level uncontrolled drop intake structure, 10-foot-diameter cast-in-place concrete service spillway conduit, a 30-inch-diameter low level gated conduit, and a Saint Anthony Falls type drop structure and stilling basin. A project location map, a vicinity map, and typical embankment sections are presented on plate 1.

3. SEISMIC EVALUATION CRITERIA.

3.1 SEISMIC HAZARD ANALYSIS. A preliminary hazard analysis has been performed for the site, based on a combined probabilistic-deterministic procedure modified from Cornell ^{1/}. Cornell's method for calculating engineering seismic risks incorporates postulated earthquake magnitudes; point, line, and areal sources; and body wave attenuation into a statistical analysis. The modified procedure incorporates the estimated magnitudes for all earthquakes within the 111-year historical record, for a 200 kilometer radius about the site, and known or inferred geologic structures. The resulting seismotectonic map, shown on plate 2, subdivides the area about the site into seismotectonic zones. Each zone is defined for a relative consistency with existing geologic features and seismicity contained within them. Seismotectonic zones capable of being significant earthquake sources were used in the preliminary analysis. The preliminary seismic hazard analysis is presented in appendix A. Detailed descriptions of the earthquakes shown on plate 2 are presented in appendix B.

3.2 POSTULATED EARTHQUAKE. For the preliminary hazard analysis, only the seismotectonic zone expected to produce the highest site acceleration was evaluated. The highest site acceleration determined by this analysis for the 1000-year recurrence earthquake would be 0.070 g. This acceleration would be due to an earthquake occurring at a 5 kilometer (km) depth along a line representing the Williston Basin axis within a 200-mile radius of Bowman-Haley Dam.

4. EMBANKMENT.

4.1 EMBANKMENT FEATURES. Bowman-Haley Dam is a rolled, homogeneous, earthfill embankment with a central impervious core flanked upstream and downstream by more pervious random zones. The embankment is 79.0 feet high at its maximum section over the channel bottom, has a crest width of 25 feet and a length of 5,730 feet. The top of the embankment was built to elevation 2794.5 feet mean sea level (m.s.l.) which included a 0.5-foot overbuild to compensate for postconstruction consolidation and foundation settlement. The upstream slope is 1 vertical (1V) on 2.5 horizontal (2.5H) from the crest to

^{1/} Cornell, C. A., "Engineering Seismic Risk Analysis," Bulletin Seismic Society of America, Vol. 58, 1968, pp. 1583-1606.

El. 2769.0, and 1V on 3H to El. 2740; and the upstream berm is 1V on 8H to original ground. The downstream slope is 1V on 2.5H from the crest to El. 2769; 1V on 3H to El. 2744; and 1V on 3.5H to original ground. Wave protection is provided for the upstream slope between elevations 2740 and the top of the embankment at elevation 2794. The protection consists of 24 inches of riprap overlying 6 inches of spalls and 6 inches of bedding. The downstream slope was covered with 9 inches of topsoil and seeded for runoff erosion control. Seepage through the embankment is controlled by an internal pervious drain. The drain has a continuous 8-foot-wide inclined section, top elevation 2781, and several horizontal outlets evenly spaced on 100-foot-centers throughout the embankment, as shown on plates 3 and 4. Typical embankment sections 1-1, 2-2, and 3-3 are shown on plate 5.

4.2 COMPACTION EQUIPMENT. The compaction equipment used on this project was approved by the Corps of Engineers' Resident Engineer. A description of the compaction equipment used during construction is presented in table 1.

TABLE 1

COMPACTION EQUIPMENT USED IN CONSTRUCTION

Tamping Roller

- (a) Bros. Self-Propelled Roller
- (b) Model SP-255D with Cat. Engine 125 H.P.
- (c) 2 Drums, 5' x 5'
- (d) Tamping Feet
 - (1) Face area = 7 sq. in.
 - (2) Length = 8 in.
 - (3) Number of teeth per drum = 120
- (e) Weight on drums water ballasted = 31,000 lbs. or 3,100 lbs. per lin. ft. of drum

Tamping Roller

- (a) Bros. Self-Propelled Roller
- (b) Model SP-255E Ser. #1102 with A.C. Engine 167 H.P.
- (c) 2 Drums
- (d) Tamping Feet
 - (1) Face area = 12 sq. in.
 - (2) Length = 8 in.
- (e) Total weight, water ballasted = 35,000 lbs.
Weight on drums = 31,000 lbs. or 3,100 lbs. per lin. ft. of drum

TABLE 1 (Cont'd)

Tamping Roller

- (a) Towed type - towed by Allis Chalmers HD-15 Tractor
- (b) Double drum = 10 lin. ft. total, each drum = 98 cu. ft.
- (c) Tamping Feet
 - (1) Face area - 8 sq. in.
 - (2) Length = 8 in.
- (d) Roller weight empty = 11,925 lbs.
Roller weight as used = 30,937 lbs. or 3,094 lbs. per lin. ft.
- (e) Ballast - right drum = old concrete sand
- left drum = Bowman Redi Mix sand

Rubber Tired Pneumatic Roller

- (a) Ferguson (4 wheel) - towed by Allis Chalmers HD-21 Dozer
- (b) 17' x 8' x 6'
- (c) Roller weight empty = 40,000 lbs.
Roller weight as used - 21,960 lbs. per wheel

Vibratory Flatwheel Roller

- (a) Vibratow II - towed by Farmall "M" Tractor
- (b) Model VT2 Ser. #786
- (c) 3' x 5' Drum

Crawler Tractor

- (a) Weight = 40,000 lbs.

It was estimated that the percent of fill compacted by the various rollers was as follows:

2 - Bros. self-propelled tamping rollers	= 65%
1 - Towed tamping roller	= 25%
1 - 4 Wheel pneumatic (towed)	= 10%
1 - Towed vibratory flatwheel & power hand tampers	= Insignificant

4.3 EMBANKMENT MATERIALS.

4.3.1 Earthfill. Material for the impervious core consists of lean clays (CL), clayey silts (ML), sandy clays (CL), and silts (ML). Material for the random zones consists of clays, silts and sands. Fat clays (CH) were used only in the upstream random fill zone. Material for berm fill is that material from required excavation which was too wet, and lignite material. Approximately 75 percent of the fill was obtained from the required spillway, outlet works, and cutoff trench excavations. The remainder of the required material, predominantly silt, was borrowed from a ridge north of the left abutment.

4.3.2 Embankment Drain Material. The material placed in the pervious fill sections of the embankment was clean, free draining sand having less than 10 percent finer than No. 200 mesh sieve size. This material was obtained from gravel terraces on the reservoir floor.

4.4 MATERIAL PLACEMENT AND COMPACTION.

4.4.1 General. Specifications required that the gradation and distribution of materials throughout the earthfill section of the dam would be such that the embankment would be free from lenses, pockets, streaks and layers of material differing substantially in texture or gradation from surrounding material. If the desired compaction of any portion of the embankment was not secured by the number of passes specified below, additional complete passes were made over the area of the designated portion until the desired compaction was obtained. Unless otherwise directed, compaction equipment was operated parallel to the axis of the dam. When approved, the Contractor was allowed to use other layer thicknesses, number of passes, and compaction equipment, provided the results were at least equal to those specified.

4.4.2 Compacted Embankment Fill. The embankment section consists of a central impervious core flanked by more pervious random zones. The materials were placed so as to provide a progressive increase in permeability from the center out toward each slope. Specifications required that the fill material be placed in approximately horizontal layers and compacted as shown in table 2.

TABLE 2

SPECIFIED COMPACTION PROCEDURES - EMBANKMENT FILL

<u>Type Fill and Compaction Equipment</u>	<u>Maximum Uncompacted Lift Thickness (Inches)</u>	<u>Minimum No. of Passes</u>
<u>Impervious Fill</u>		
Rubber-tired roller	12	3
Tamping roller	8	6
Power tampers	4	As Required to Obtain Desired Densities
<u>Random Fill</u>		
Rubber-tired roller	12	3
Tamping roller	8	6
Power tampers	4	As Required to Obtain Desired Densities

It was intended that the above procedures would provide a final density of at least 95% of maximum density. The moisture content was required to be within 2 percent above optimum moisture content to 4 percent below optimum. The optimum moisture content was determined in accordance with AASHTO Standard T 99-57, Method "A". Field density was determined by sand cone, water balloon, and nuclear density methods. Portions of the fill which could not be compacted with rollers because of space restrictions, were placed in 4-inch loose lift layers and compacted with power tampers to the desired density.

4.4.3 Semicompacted Berms. The material for berm fill was material from required excavation that was unsuitable for compacted fill. This included material which was too wet, and lignite. Specifications required that the semicompacted berms be constructed in layers not exceeding 24 inches in thickness, except for the lignite. The lignite was placed in the berm as directed and spread in horizontal layers with an uncompacted thickness of 12 inches. Each lignite layer was compacted by four passes of the tamper type roller. Compaction for the other materials was accomplished by even routing of construction and hauling equipment over the layers. Moisture control was not specified, except that the upper limit could not exceed that which would permit the movement of equipment over the fill.

4.4.4 Pervious Fill. Pervious fill was dumped and spread to an uncompacted thickness of not more than 12 inches and was wetted, as directed, to facilitate compaction. The amount of water added to the material was approximately that which would produce substantial saturation when the material was in the compacted state. The entire surface of each layer was compacted by not less than three complete passes of rubber-tired rollers. A small percentage of the pervious fill was compacted, as directed, by a vibratory roller, and an even smaller percentage by a 40,000-lb. crawler tractor. A maximum uncompacted lift thickness of 4 inches and a minimum number of four complete passes were required when compacting with the crawler tractor.

4.5 EVALUATION OF EMBANKMENT LIQUEFACTION POTENTIAL. The construction records indicate that the central core of the embankment is comprised of impervious material and therefore, not subject to liquefaction. The construction records also indicate that the random fill sections that buttress the central core and the pervious fill were properly compacted to assure satisfactory performance. These materials are considered to have

adequate resistance to postulated earthquake shaking, since it is generally agreed that virtually any well-built embankment can withstand moderate earthquake shaking with peak accelerations of 0.2 g and more with no detrimental effects.

5. FOUNDATION.

5.1 FOUNDATION EXPLORATIONS. The subsurface exploration program at Bowman-Haley Dam consisted of drilling 33 borings to varying depths, ranging from 18 to 114 feet. The purpose of the exploration program was to determine the embankment and outlet works foundation as well as borrow and emergency spillway area soil characteristics. Four initial borings were drilled in the right bank spillway location in the fall of 1959. The remaining borings were completed during 1963. These were located along the embankment centerline, in the outlet works location, in the right bank spillway location, and the alternate spillway location on the left bank. Disturbed jar and moisture samples were taken from these borings at every change of material and at intervals not greater than 5 feet in depth.

The locations of borings in the vicinity of the embankment centerline are shown in plan on plates 3 and 4 and in profile 4-4 presented on plate 6.

5.2 FOUNDATION CONDITIONS. The foundation at the dam site consists of alluvial soils in the flood plain and residual soils in the abutments. Ludlow Formation (bedrock) underlies these surface soils. The alluvium varies in thickness from about 2 to 25 feet and is predominantly fine sand and silty sand with minor amounts of lean and sandy clay, underlain by gravelly sand, clayey gravel and sandy gravel. The residual material mantles the abutments to a thickness of 0 to 5 feet and is generally friable, lean clay and fat clay. A gravel terrace overlain by colluvium is located in the left abutment and underlies a section of the embankment. At the centerline the gravel deposit is 1 to 3 feet thick. The Ludlow Formation is composed of soft to very stiff clays; medium dense to very dense, fine-grained sands; soft to hard, thin-bedded sandstones; soft shales and soft to hard lignites. The Ludlow is described primarily by soil terminology due to the poorly indurated characteristics of the material.

5.3 FOUNDATION DESIGN. Positive underseepage control was provided in the valley section from Sta. 29+00 to Sta. 60+00 by a cutoff trench through the alluvial sand and gravel. The bottom of the cutoff trench was raised and lowered in the field, as directed, to establish the trench bottom at the bottom of lignite layer "A" which overlies an impervious clayey sand horizon. The trench was excavated with 1 on 1 side slopes and a 25-foot bottom width, and backfilled with impervious material. A somewhat shallower trench with 1 on 1 side slopes and a 25-foot bottom width extending only through the sandy gravel zone and not to the "A" lignite layer was provided in the left abutment from Station 60+00 to Station 70+00. Since completion of the project, four seeps have developed along the "A" lignite layer in the left bank of the discharge channel near the stilling basin. No seeps have developed along the right bank. Seepage in this area is controlled by the cutoff trench which extends throughout the "A" lignite layer. The cutoff trenches are shown in the embankment profile presented on plate 6.

6. PROPOSED ADDITIONAL WORK TO COMPLETE SEISMIC EVALUATION.

6.1 FIELD INVESTIGATION. Standard Penetration Test (SPT) data, necessary to determine the potential of the valley foundation sands and gravels to resist liquefaction during earthquake shaking, are not available. The proposed initial field investigation would consist of seven Standard Penetration Test (SPT) borings drilled along the downstream toe of the dam. Continuous SPT results with split spoon samples would be obtained from each boring for the full 25-foot depth of the valley alluvium. The plan of proposed borings is presented on plates 3 and 4. Geologic sections 5-5 through 12-12, shown in plan view on plates 3 and 4 and in cross section on plates 7 and 8, are considered representative of foundation materials at the site. These cross sections also show the various reaches of the foundation proposed for initial investigation. The final field investigation, if necessary, would consist of companion borings that would generally recover representative, undisturbed sand and silt samples for laboratory cyclic triaxial testing.

6.2 LABORATORY ANALYSIS. Laboratory classification tests would be performed on all jar samples and undisturbed samples obtained from the exploratory borings. Mechanical Analysis Tests to the D_{10} grain size would

be performed on all samples having a Unified Soil Classification of poorly graded Sand or Gravel (SP), well graded Sand or Gravel (SW), Silty Sand (SM-SP or SM), and Silt (^{ML}SM). Cyclic Triaxial Tests and relative Density Tests would be performed on representative specimens of these nonplastic (cohesionless) materials. Atterberg Limits Tests, Moisture Tests, and Gradation Tests would be performed on all clayey materials to determine vulnerability to severe strength loss as a result of earthquake shaking. These soils are considered to have the following characteristics:

Percent finer than 0.005 mm sieve	<15%
Liquid Limit	<35
Water Content	>0.9 x Liquid Limit

If soils with these characteristics plot above the A-line on the plasticity chart, their cyclic loading characteristics would be determined by Cyclic Triaxial Tests.

6.3 EVALUATION OF DATA TO DETERMINE FOUNDATION LIQUEFACTION POTENTIAL. A procedure suggested by Seed ^{2/} would be used to evaluate foundation liquefaction potential. This procedure compares the cyclic shear strength resisting liquefaction, based on corrected SPT data, with the average shear stress induced by the postulated earthquake. These corrected blow counts would be increased by 7.5, as appropriate, using procedures developed in a recent study by Seed and Idriss ^{3/}, which verified that certain silts and silty sands are less vulnerable to liquefaction than sands with similar corrected SPT resistance values. The foundation soil layers would be considered seismically stable when the computed safety factor is greater than 1.5, using this procedure.

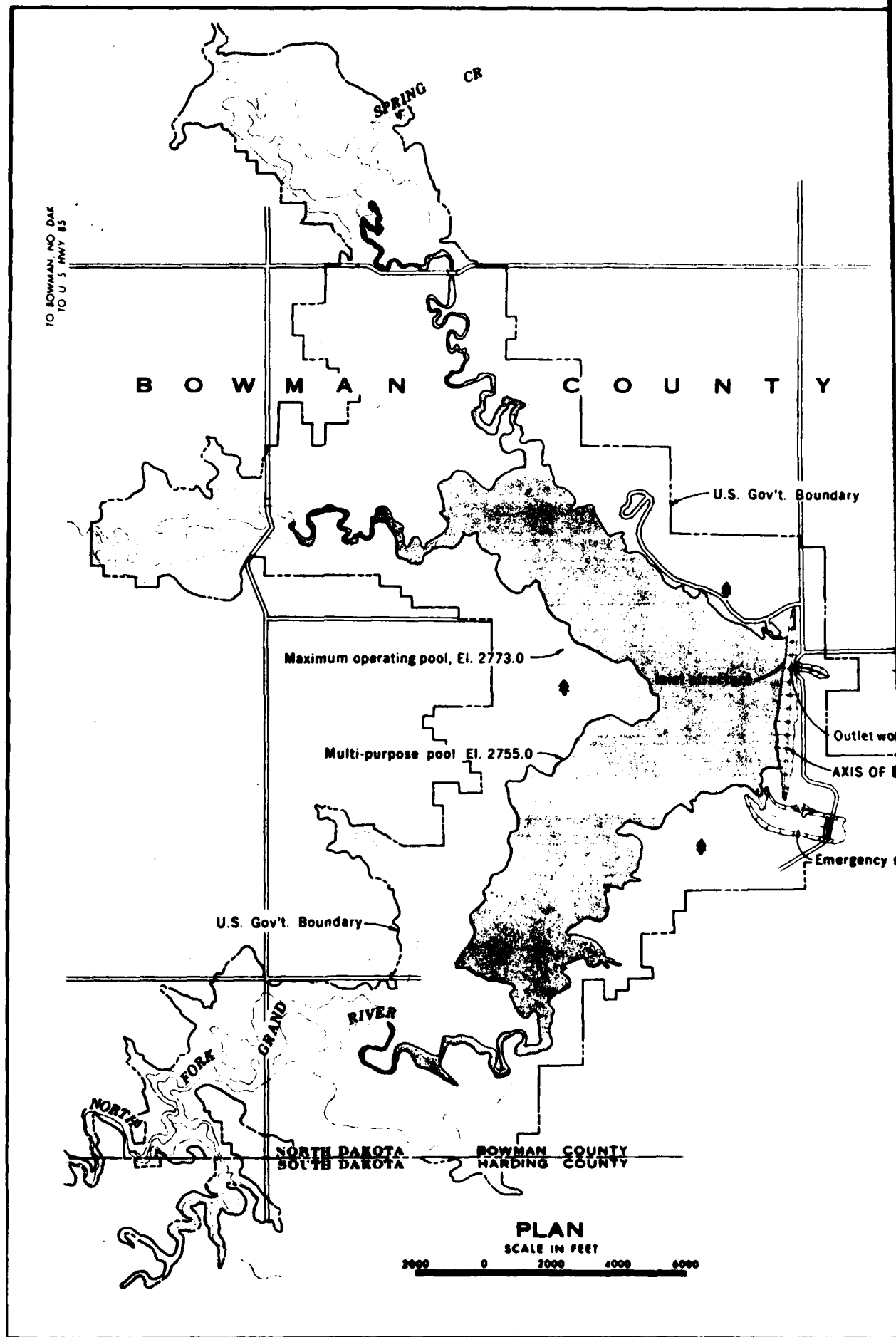
^{2/} Seed, H. B., "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground During Earthquakes," Journal of the Geotechnical Engineering Division, ASCE Vol. 105, No. GT2, Feb. 1979, pp. 201-255.

^{3/} Seed, H. B., Idriss, I. M., "Evaluation of Liquefaction Potential of Sand Deposits Based on Observations of Performance in Previous Earthquakes," In-Situ Testing to Evaluate Liquefaction Susceptibility, ASCE Conference, St. Louis, Oct. 26-31, 1981 (Preprint).

6.4 COST ESTIMATE FOR INITIAL SEISMIC EVALUATION REPORT.

Drilling Costs	\$ 33,000
Laboratory Costs	10,000
Office and Reproduction Costs	<u>15,000</u>
Total Cost	\$ 58,000

7. **RECOMMENDATION.** Presently \$50,000 is scheduled during FY 84 for preparation of the Seismic Evaluation Report for the Bowman-Haley Dam project. It is recommended that this reconnaissance report be approved as a basis for preparation of the Initial Report.





C O U N T Y

U.S. Gov't. Boundary

Outlet works

AXIS OF DAM

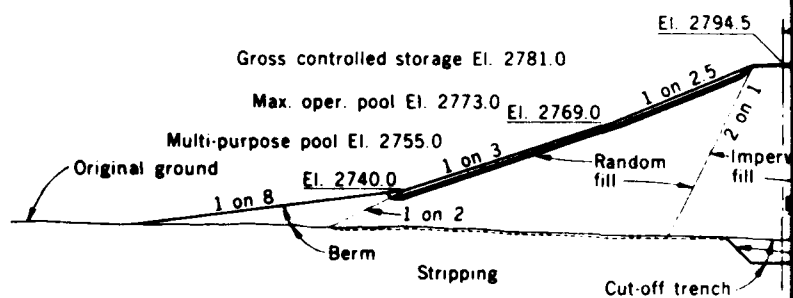
Emergency spillway

CO. COUNTY

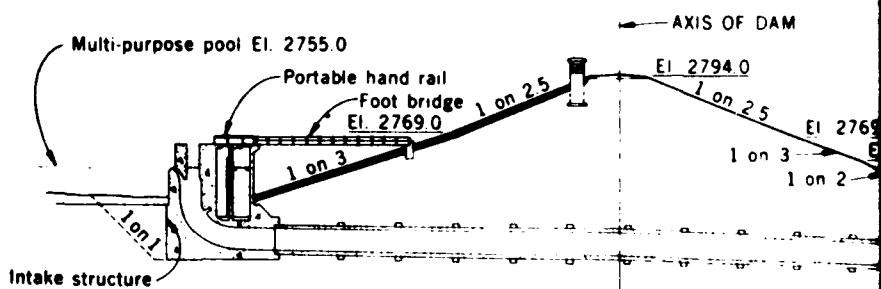
PLAN

1:25,000

0 1000 2000

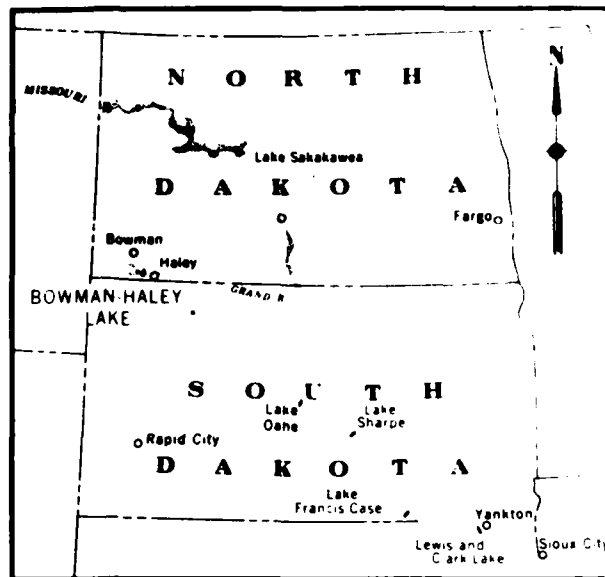


EMBANKMENT SECTION

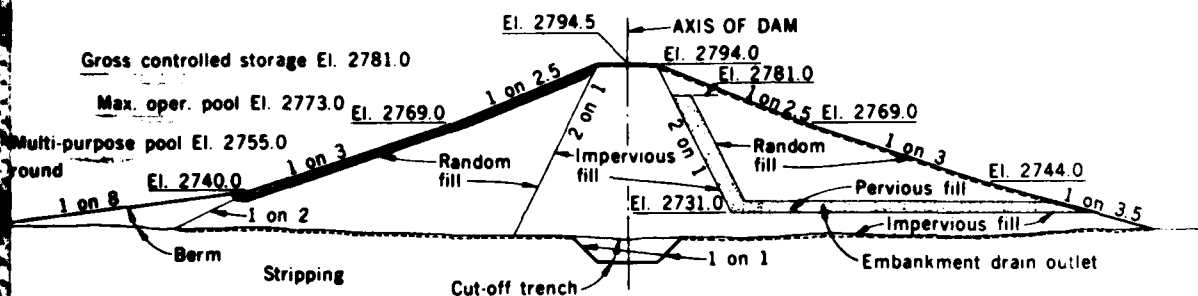


OUTLET WORKS SECTION

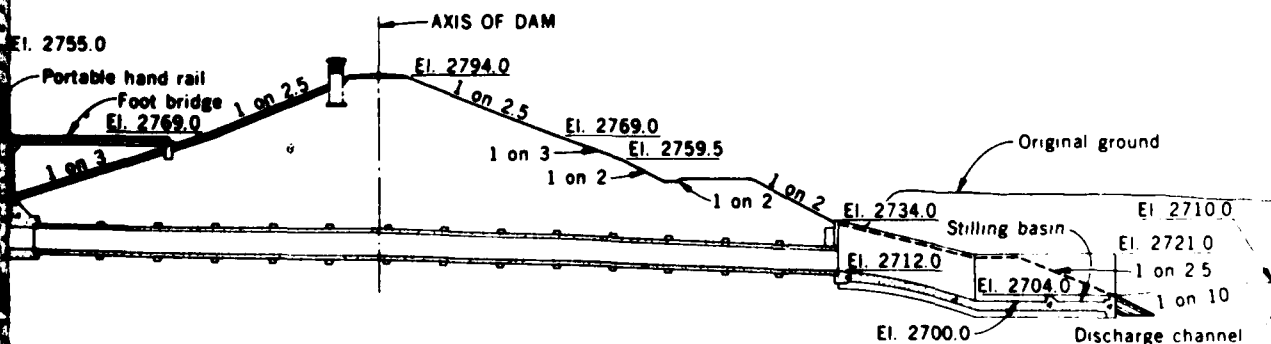
VICINITY



LOCATION MAP

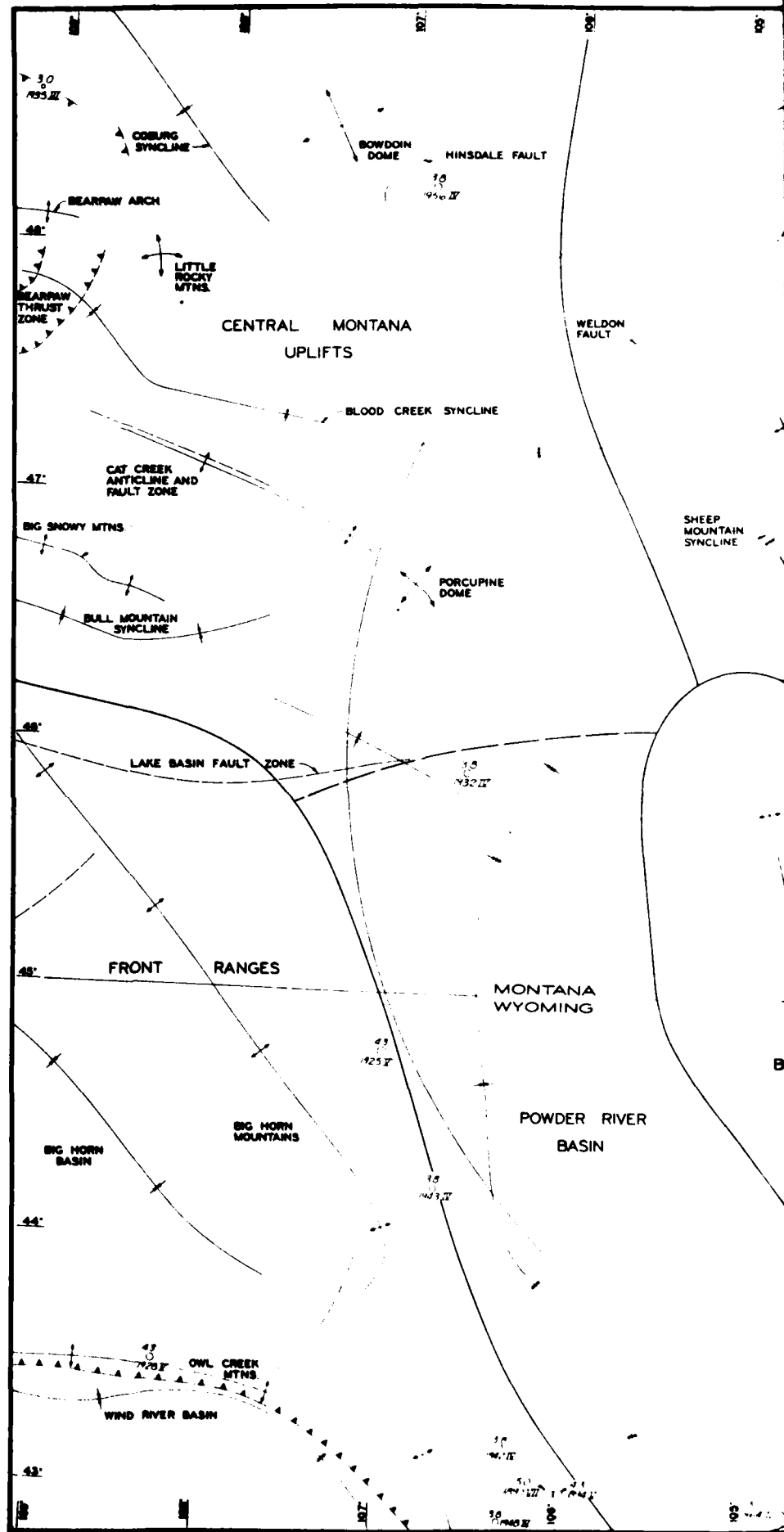


EMBANKMENT SECTION



OUTLET WORKS PROFILE

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
 BOWMAN - HALEY DAM AND LAKE
 RECONNAISSANCE REPORT
 SEISMIC EVALUATION AND ANALYSIS
 VICINITY MAP, LOCATION MAP AND TYPICAL SECTIONS
 U.S. ARMY ENGINEER DISTRICT, OMAHA
 CORPS OF ENGINEERS OMAHA, NEBRASKA



ILLISTON BASIN

DAKOTA
DAKOTA

BASEMENT SLOPE

POSSIBLE
SUPERIOR-CHURCHILL
PRECAMBRIAN TERRANE
BOUNDARY

THIS DRAWING HAS BEEN REDUCED TO
THREE-FOURTHS THE ORIGINAL SCALE

LEGEND:

EARTHQUAKE EPICENTRAL LOCATIONS

- $M_b < 3.0$
 - $M_b = 3.0-3.5$
 - $M_b = 3.6-4.0$
 - $M_b = 4.1-4.5$
 - $M_b = 4.6-5.0$
 - $M_b > 5.0$
- M_b = BODY WAVE MAGNITUDE
CONVERTED FROM
INTENSITY, UNLESS
OTHERWISE NOTED

BODY WAVE MAGNITUDE SUPERSCRIPT INDICATES NUMBER OF SMALLER
FORESHOCKS OR AFTERSHOCKS IN SAME VICINITY AS MAIN SHOCK
DATE OF EVENT WITH MODIFIED MERCALLI INTENSITY
INTENSITY AND LOCATION DETERMINED BY RELATIVE EFFECTS
MAGNITUDE AND LOCATION INSTRUMENTALLY DETERMINED

- INFERRED BASEMENT FAULT OR TERRANE BOUNDARY
- MAPPED FAULT
- ▲▲▲ MAPPED THRUST FAULT BARBS ON UPTHROWN SIDE
- SEISMOTECTONIC PROVINCE BOUNDARY
- SEISMOTECTONIC SUBPROVINCE BOUNDARY
- SYNCLINAL OR BASIN AXIS
- ANTICLINAL OR UPLIFT AXIS

MILES
KILOMETERS

NORTH FORK OF GRAND RIVER NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
SEISMOTECTONIC PROVINCE AND
SEISMICITY MAP FOR NORTH DAKOTA AND
PORTIONS OF ADJACENT STATES

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

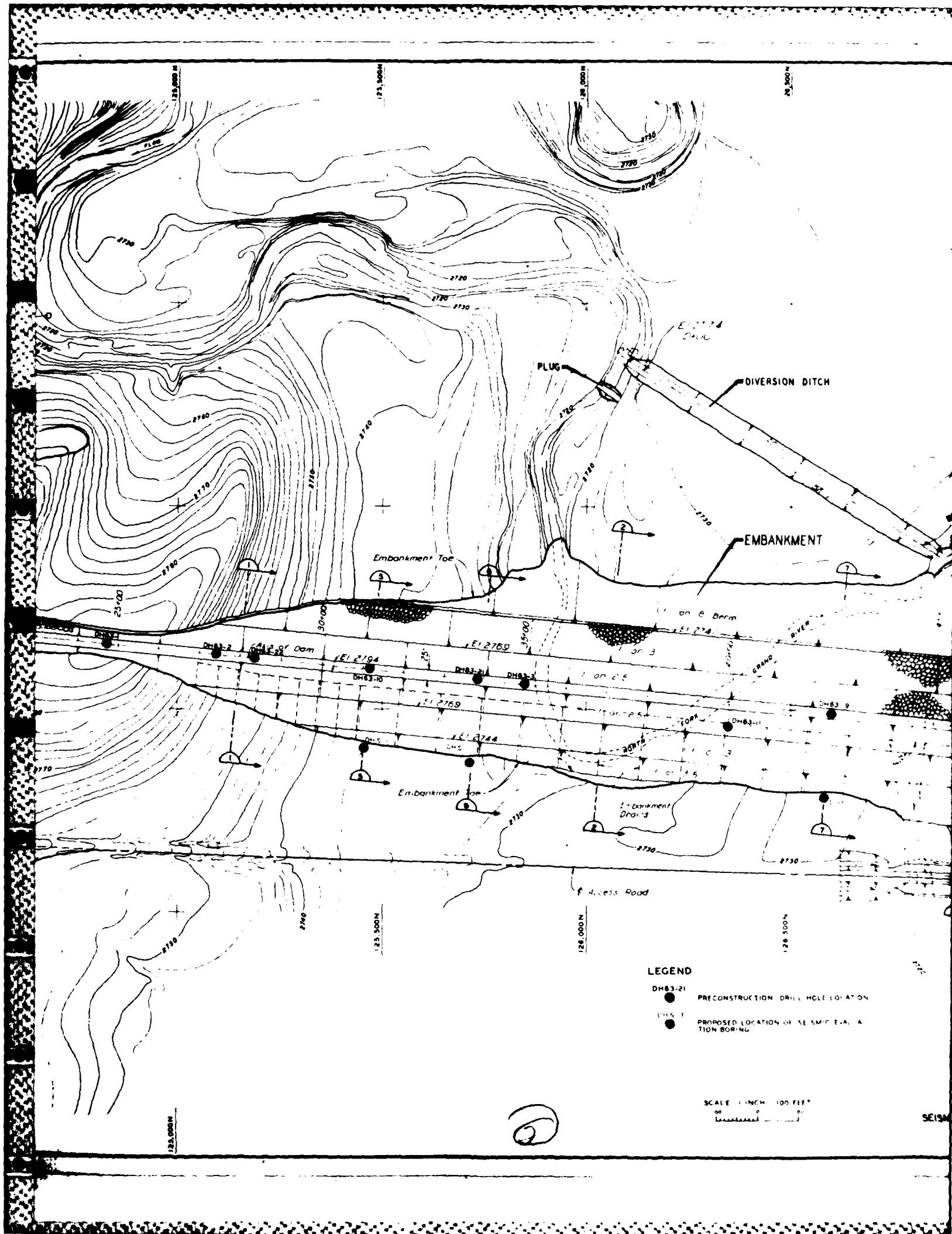
PLATE 2

3

This is a topographic map of a spillway area. The map features contour lines indicating elevation, with labels such as 2700, 2710, 2720, 2730, 2740, 2750, 2760, 2770, 2780, 2790, 2800, 2810, 2820, 2830, 2840, 2850, 2860, 2870, 2880, 2890, 2900, 2910, 2920, 2930, 2940, 2950, 2960, 2970, 2980, 2990, 3000, 3010, 3020, 3030, 3040, 3050, 3060, 3070, 3080, 3090, 3100, 3110, 3120, 3130, 3140, 3150, 3160, 3170, 3180, 3190, 3200, 3210, 3220, 3230, 3240, 3250, 3260, 3270, 3280, 3290, 3300, 3310, 3320, 3330, 3340, 3350, 3360, 3370, 3380, 3390, 3400, 3410, 3420, 3430, 3440, 3450, 3460, 3470, 3480, 3490, 3500, 3510, 3520, 3530, 3540, 3550, 3560, 3570, 3580, 3590, 3600, 3610, 3620, 3630, 3640, 3650, 3660, 3670, 3680, 3690, 3700, 3710, 3720, 3730, 3740, 3750, 3760, 3770, 3780, 3790, 3800, 3810, 3820, 3830, 3840, 3850, 3860, 3870, 3880, 3890, 3900, 3910, 3920, 3930, 3940, 3950, 3960, 3970, 3980, 3990, 4000, 4010, 4020, 4030, 4040, 4050, 4060, 4070, 4080, 4090, 4100, 4110, 4120, 4130, 4140, 4150, 4160, 4170, 4180, 4190, 4200, 4210, 4220, 4230, 4240, 4250, 4260, 4270, 4280, 4290, 4300, 4310, 4320, 4330, 4340, 4350, 4360, 4370, 4380, 4390, 4400, 4410, 4420, 4430, 4440, 4450, 4460, 4470, 4480, 4490, 4500, 4510, 4520, 4530, 4540, 4550, 4560, 4570, 4580, 4590, 4600, 4610, 4620, 4630, 4640, 4650, 4660, 4670, 4680, 4690, 4700, 4710, 4720, 4730, 4740, 4750, 4760, 4770, 4780, 4790, 4800, 4810, 4820, 4830, 4840, 4850, 4860, 4870, 4880, 4890, 4900, 4910, 4920, 4930, 4940, 4950, 4960, 4970, 4980, 4990, 5000, 5010, 5020, 5030, 5040, 5050, 5060, 5070, 5080, 5090, 5100, 5110, 5120, 5130, 5140, 5150, 5160, 5170, 5180, 5190, 5200, 5210, 5220, 5230, 5240, 5250, 5260, 5270, 5280, 5290, 5300, 5310, 5320, 5330, 5340, 5350, 5360, 5370, 5380, 5390, 5400, 5410, 5420, 5430, 5440, 5450, 5460, 5470, 5480, 5490, 5500, 5510, 5520, 5530, 5540, 5550, 5560, 5570, 5580, 5590, 5600, 5610, 5620, 5630, 5640, 5650, 5660, 5670, 5680, 5690, 5700, 5710, 5720, 5730, 5740, 5750, 5760, 5770, 5780, 5790, 5800, 5810, 5820, 5830, 5840, 5850, 5860, 5870, 5880, 5890, 5900, 5910, 5920, 5930, 5940, 5950, 5960, 5970, 5980, 5990, 6000, 6010, 6020, 6030, 6040, 6050, 6060, 6070, 6080, 6090, 6100, 6110, 6120, 6130, 6140, 6150, 6160, 6170, 6180, 6190, 6200, 6210, 6220, 6230, 6240, 6250, 6260, 6270, 6280, 6290, 6300, 6310, 6320, 6330, 6340, 6350, 6360, 6370, 6380, 6390, 6400, 6410, 6420, 6430, 6440, 6450, 6460, 6470, 6480, 6490, 6500, 6510, 6520, 6530, 6540, 6550, 6560, 6570, 6580, 6590, 6600, 6610, 6620, 6630, 6640, 6650, 6660, 6670, 6680, 6690, 6700, 6710, 6720, 6730, 6740, 6750, 6760, 6770, 6780, 6790, 6800, 6810, 6820, 6830, 6840, 6850, 6860, 6870, 6880, 6890, 6900, 6910, 6920, 6930, 6940, 6950, 6960, 6970, 6980, 6990, 7000, 7010, 7020, 7030, 7040, 7050, 7060, 7070, 7080, 7090, 7100, 7110, 7120, 7130, 7140, 7150, 7160, 7170, 7180, 7190, 7200, 7210, 7220, 7230, 7240, 7250, 7260, 7270, 7280, 7290, 7300, 7310, 7320, 7330, 7340, 7350, 7360, 7370, 7380, 7390, 7400, 7410, 7420, 7430, 7440, 7450, 7460, 7470, 7480, 7490, 7500, 7510, 7520, 7530, 7540, 7550, 7560, 7570, 7580, 7590, 7600, 7610, 7620, 7630, 7640, 7650, 7660, 7670, 7680, 7690, 7700, 7710, 7720, 7730, 7740, 7750, 7760, 7770, 7780, 7790, 7800, 7810, 7820, 7830, 7840, 7850, 7860, 7870, 7880, 7890, 7900, 7910, 7920, 7930, 7940, 7950, 7960, 7970, 7980, 7990, 8000, 8010, 8020, 8030, 8040, 8050, 8060, 8070, 8080, 8090, 8100, 8110, 8120, 8130, 8140, 8150, 8160, 8170, 8180, 8190, 8200, 8210, 8220, 8230, 8240, 8250, 8260, 8270, 8280, 8290, 8300, 8310, 8320, 8330, 8340, 8350, 8360, 8370, 8380, 8390, 8400, 8410, 8420, 8430, 8440, 8450, 8460, 8470, 8480, 8490, 8500, 8510, 8520, 8530, 8540, 8550, 8560, 8570, 8580, 8590, 8600, 8610, 8620, 8630, 8640, 8650, 8660, 8670, 8680, 8690, 8700, 8710, 8720, 8730, 8740, 8750, 8760, 8770, 8780, 8790, 8800, 8810, 8820, 8830, 8840, 8850, 8860, 8870, 8880, 8890, 8900, 8910, 8920, 8930, 8940, 8950, 8960, 8970, 8980, 8990, 9000, 9010, 9020, 9030, 9040, 9050, 9060, 9070, 9080, 9090, 9100, 9110, 9120, 9130, 9140, 9150, 9160, 9170, 9180, 9190, 9200, 9210, 9220, 9230, 9240, 9250, 9260, 9270, 9280, 9290, 9300, 9310, 9320, 9330, 9340, 9350, 9360, 9370, 9380, 9390, 9400, 9410, 9420, 9430,

A 105 Micro-master Film or a Paper Reproducible Record
Copy Must Be Made Before Every Amendment and/or Modification

A 105 Microfiche Film or a Paper Reproducible Record Copy Must Be Made Before Every Amendment and/or Modification	
AMENDMENT	
DATE	
MODIFICATION	
DATE	



U. S. ARMY

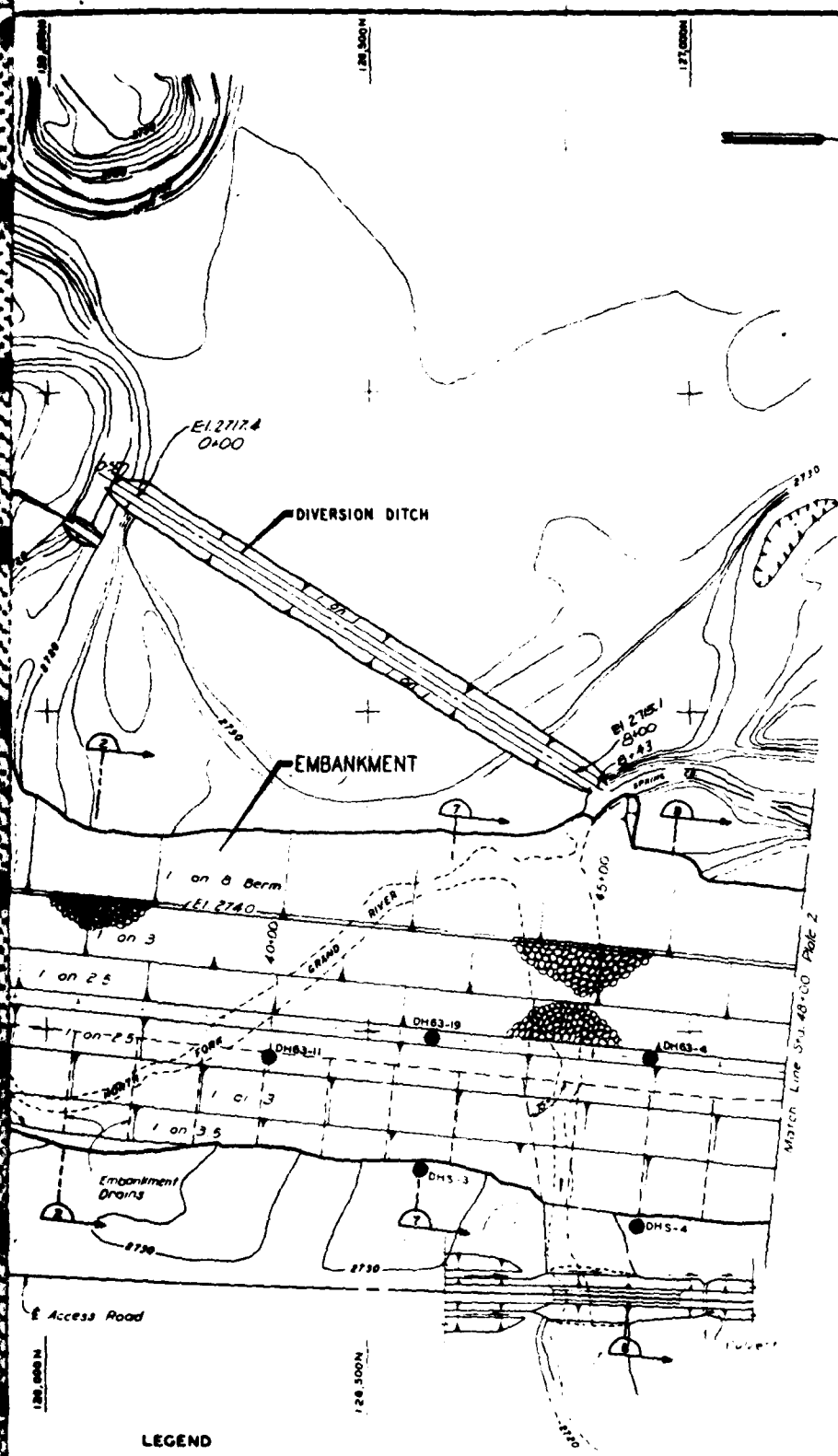
1,300,500 E

1,301,000 E

1,301,500 E

1,302,000 E

1,302,500 E



LEGEND

- DH63-21 PRECONSTRUCTION DRILL HOLE LOCATION
- DH5-3 PROPOSED LOCATION OF SEISMIC EVALUATION BORING

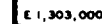
SCALE 1 INCH = 100 FEET

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
 BOWMAN-HALEY DAM AND LAKE
 RECONNAISSANCE REPORT
 SEISMIC EVALUATION AND ANALYSIS
 EMBANKMENT PLAN WITH ORIGINAL AND PROPOSED
 SEISMIC EVALUATION FOUNDATION EXPLORATIONS (SHEET 1 OF 2)
 U.S. ARMY ENGINEER DISTRICT, OMAHA
 CORPS OF ENGINEERS OMAHA, NEBRASKA

PLATE 3

3

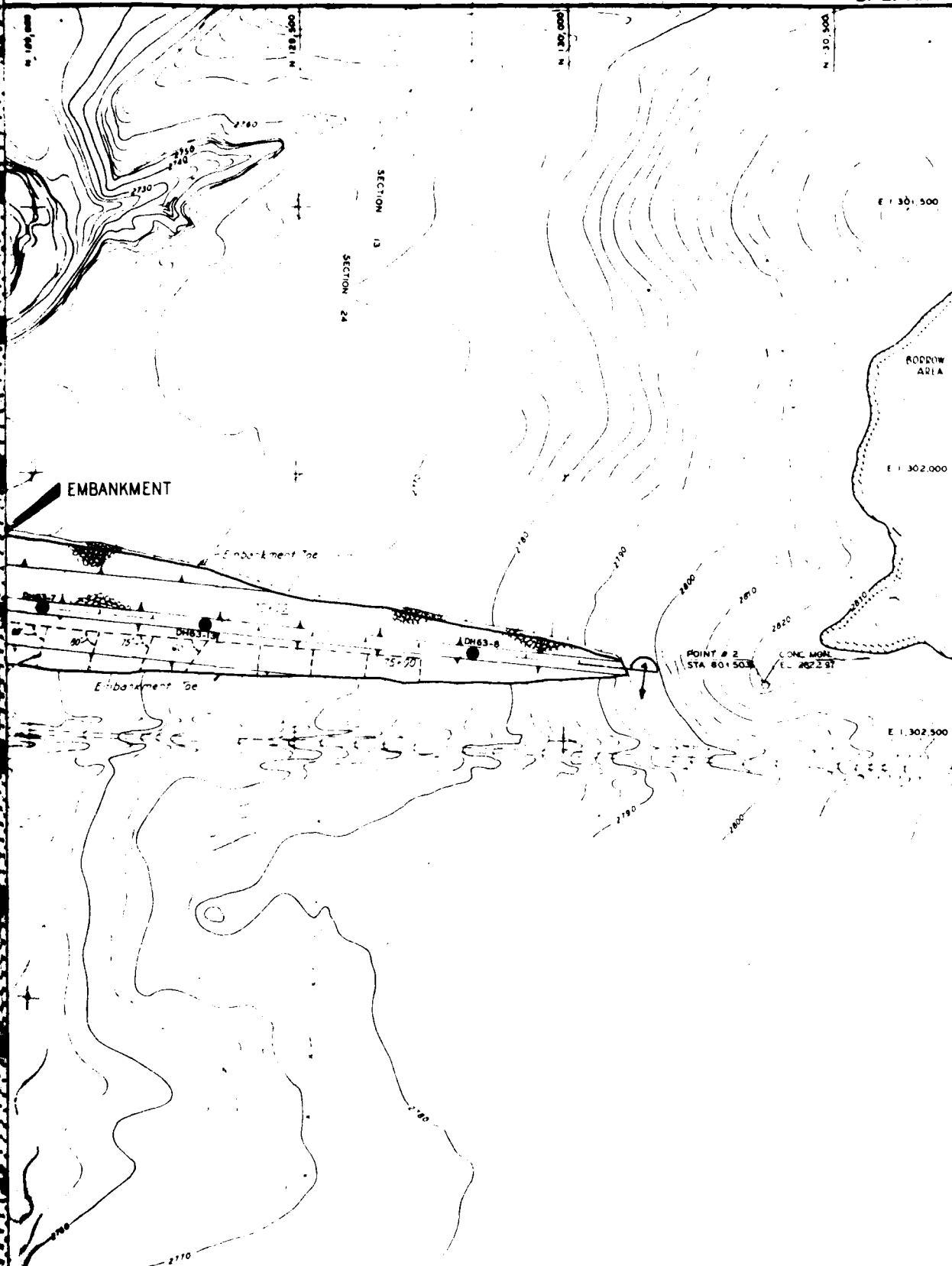
27 500



A 35 Micro-mater Film or a Paper Reproducible Record	
Copy Must Be Made Before Every Amendment and for Modification	
ASSEMBLY	
DATE	
MODIFICATION	
DATE	





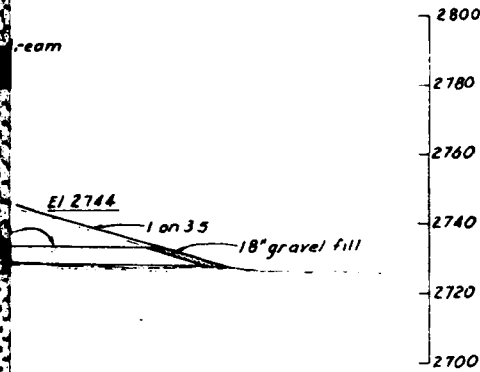
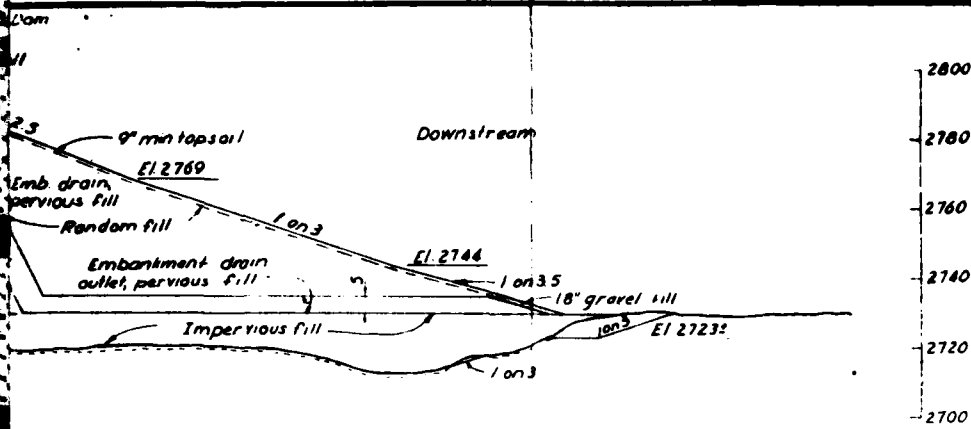


SCALE 1 INCH = 100 FEET
 100 0 100
 100 0 100

28.500

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
 BOWMAN-HALEY DAM AND LAKE
 RECONNAISSANCE REPORT
 SEISMIC EVALUATION AND ANALYSIS
 EMBANKMENT PLAN WITH ORIGINAL AND PROPOSED
 SEISMIC EVALUATION FOUNDATION EXPLORATIONS (SHEET 2 OF 2)

U.S. ARMY ENGINEER DISTRICT, OMAHA
 CORPS OF ENGINEERS OMAHA, NEBRASKA

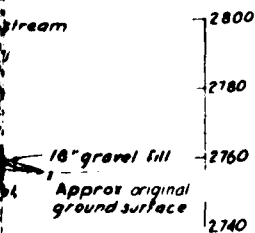
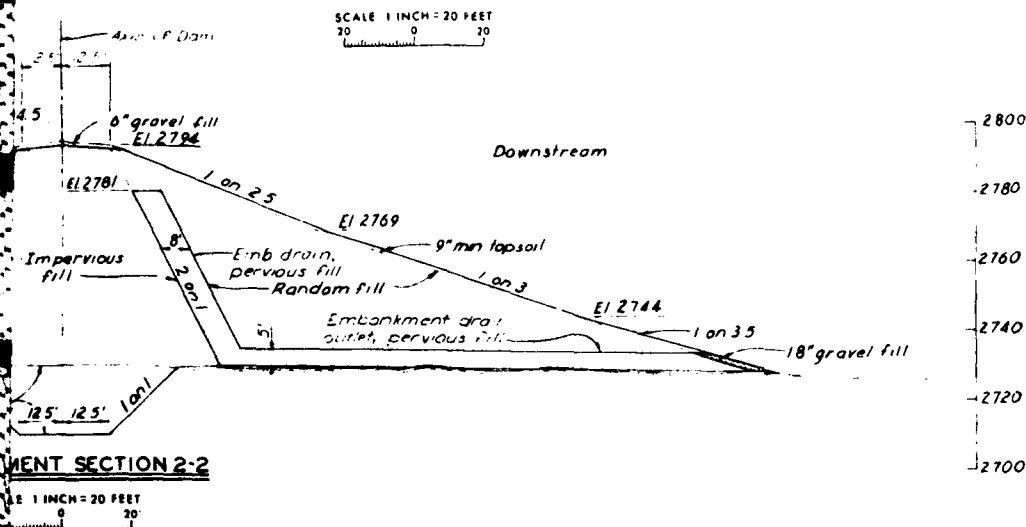
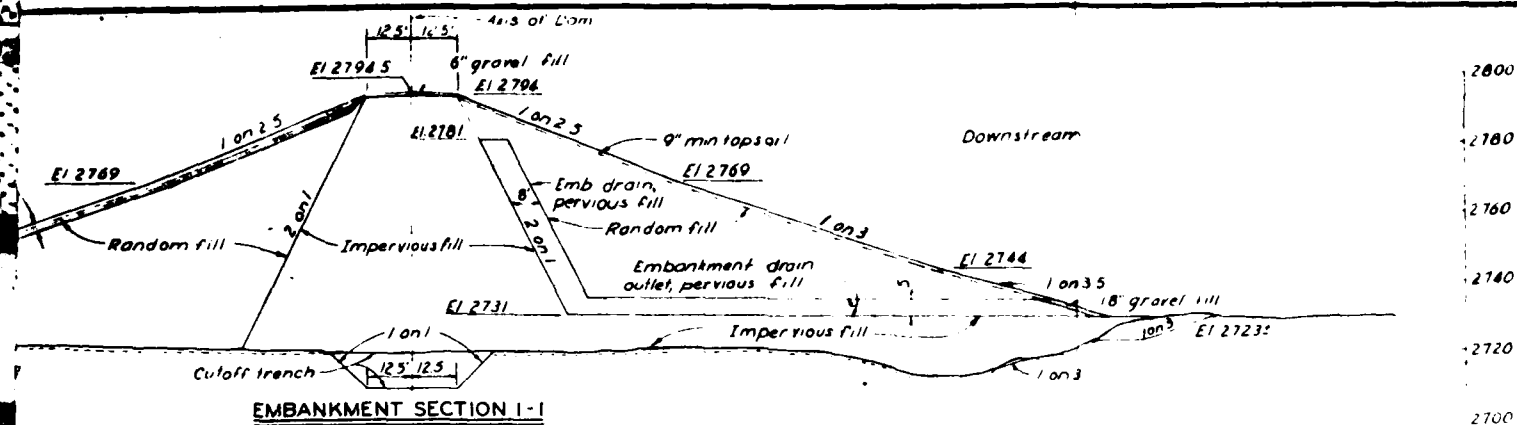


THIS DRAWING HAS BEEN REDUCED TO
THREE-EIGHTHS THE ORIGINAL SCALE.

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

EMBANKMENT SECTIONS 1-1, 2-2 AND 3-3

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



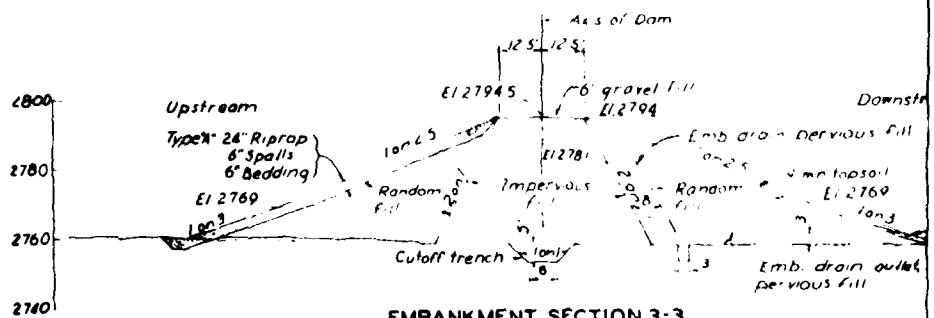
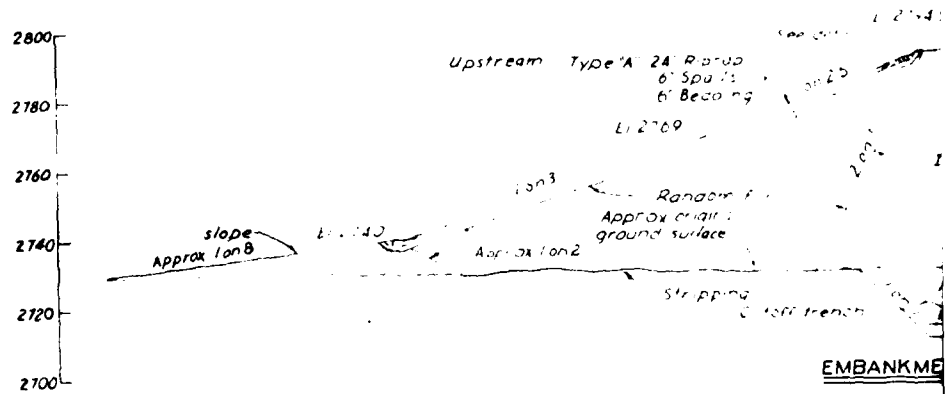
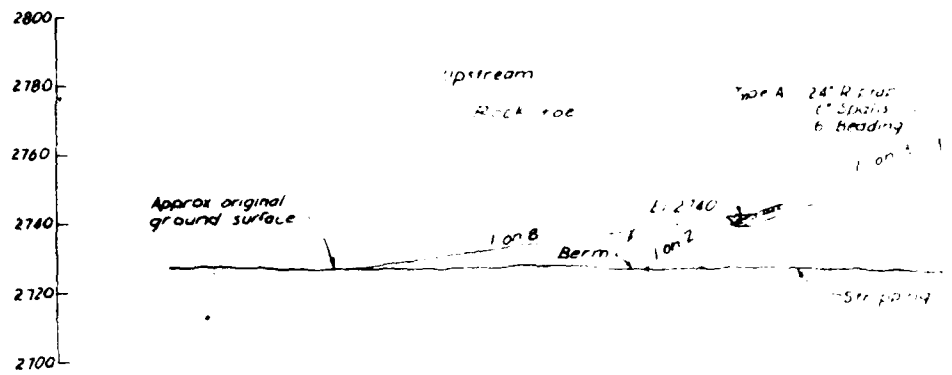
THIS DRAWING HAS BEEN REDUCED TO
THREE-FIFTHS THE ORIGINAL SCALE

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

EMBANKMENT SECTIONS 1-1, 2-2 AND 3-3

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

APPROPRIATE
DATE
MODIFICATION
DATE

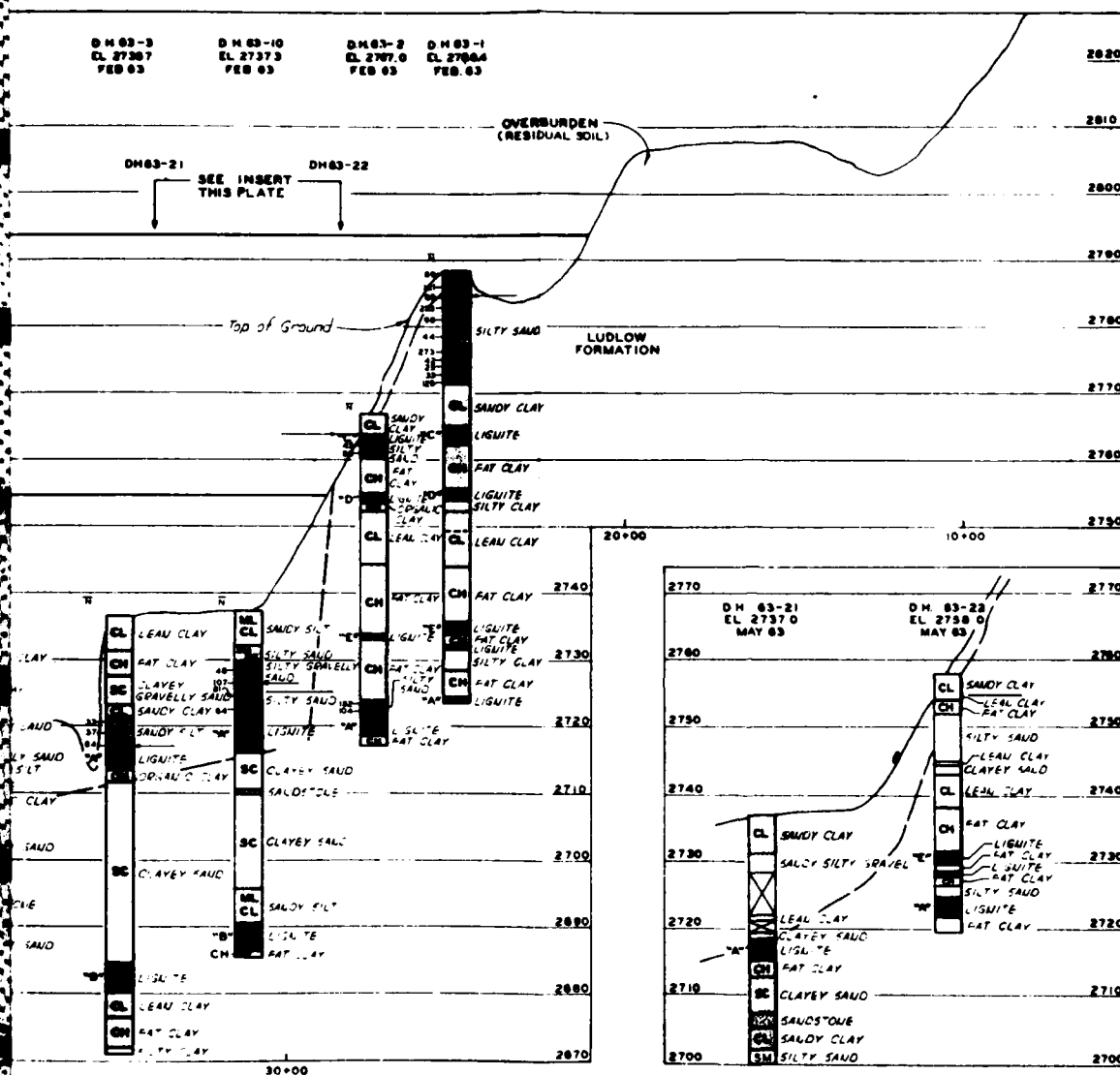


EMBANKMENT SECTION 3-3

SCALE 1 INCH 20 FEET



ON



INSERT

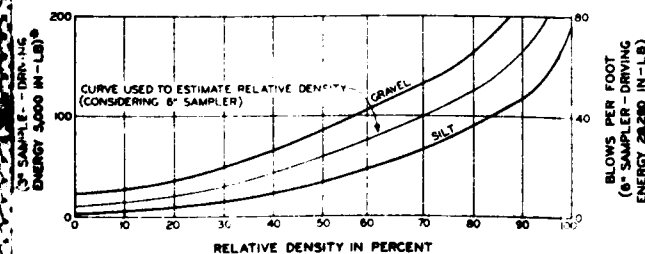


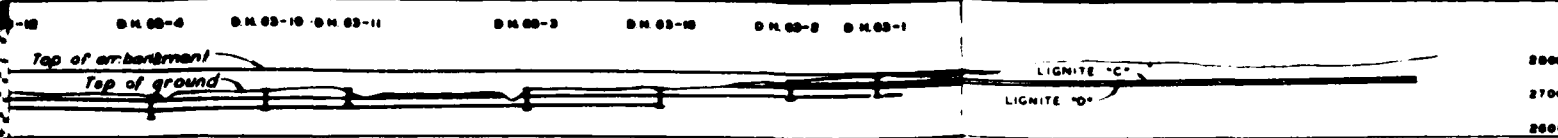
FIG 1 - RELATIONS BETWEEN DRIVING RESISTANCE OF SAMPLER IN BLOWS PER FOOT AND RELATIVE DENSITY FOR GRANULAR SOILS

● REF BURMISTER, D.M., 1940 - "PRACTICAL METHODS FOR THE CLASSIFICATION OF SOILS." PURDUE CSMFE, P 129

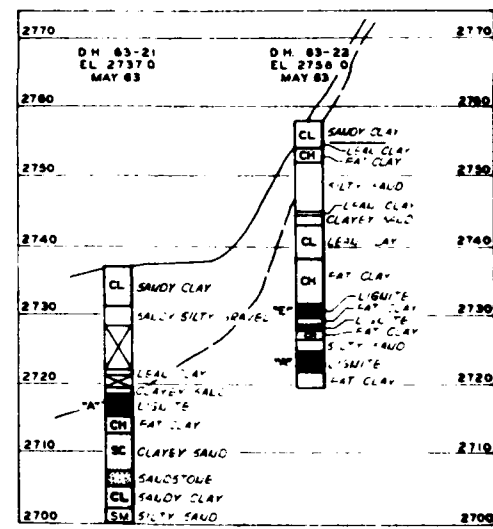
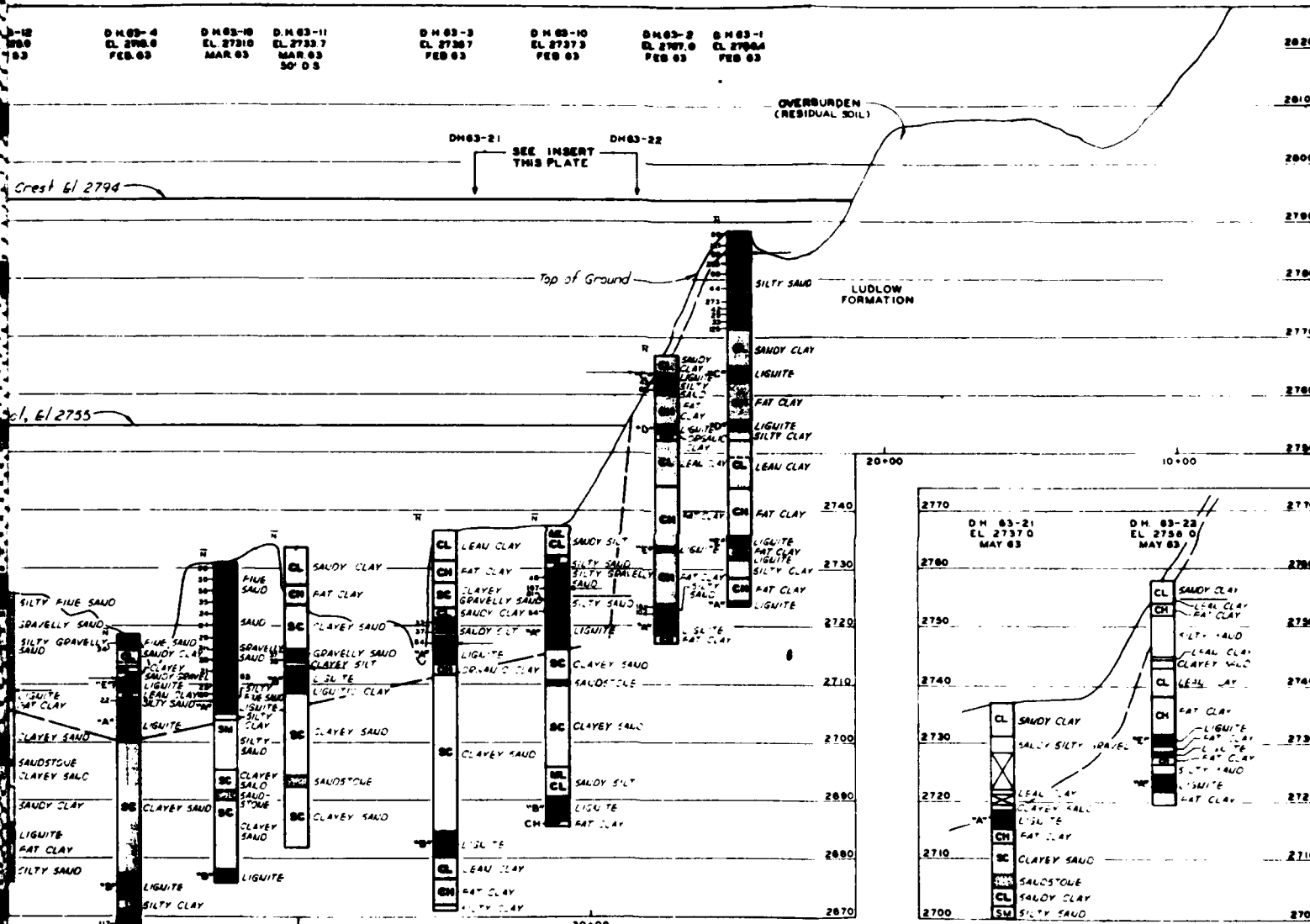
NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-MALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

GEOLOGIC PROFILE ALONG EMBANKMENT C, SECTION 4-4

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



UNDISTORTED SECTION
SCALE 1 INCH = 200 FEET



INSERT

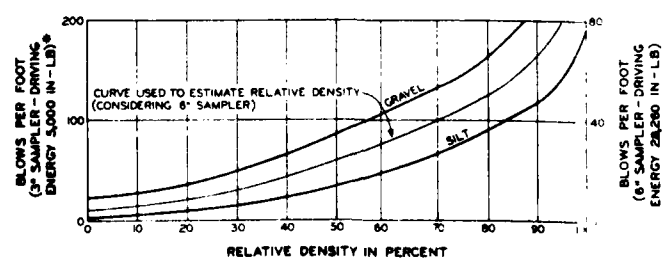


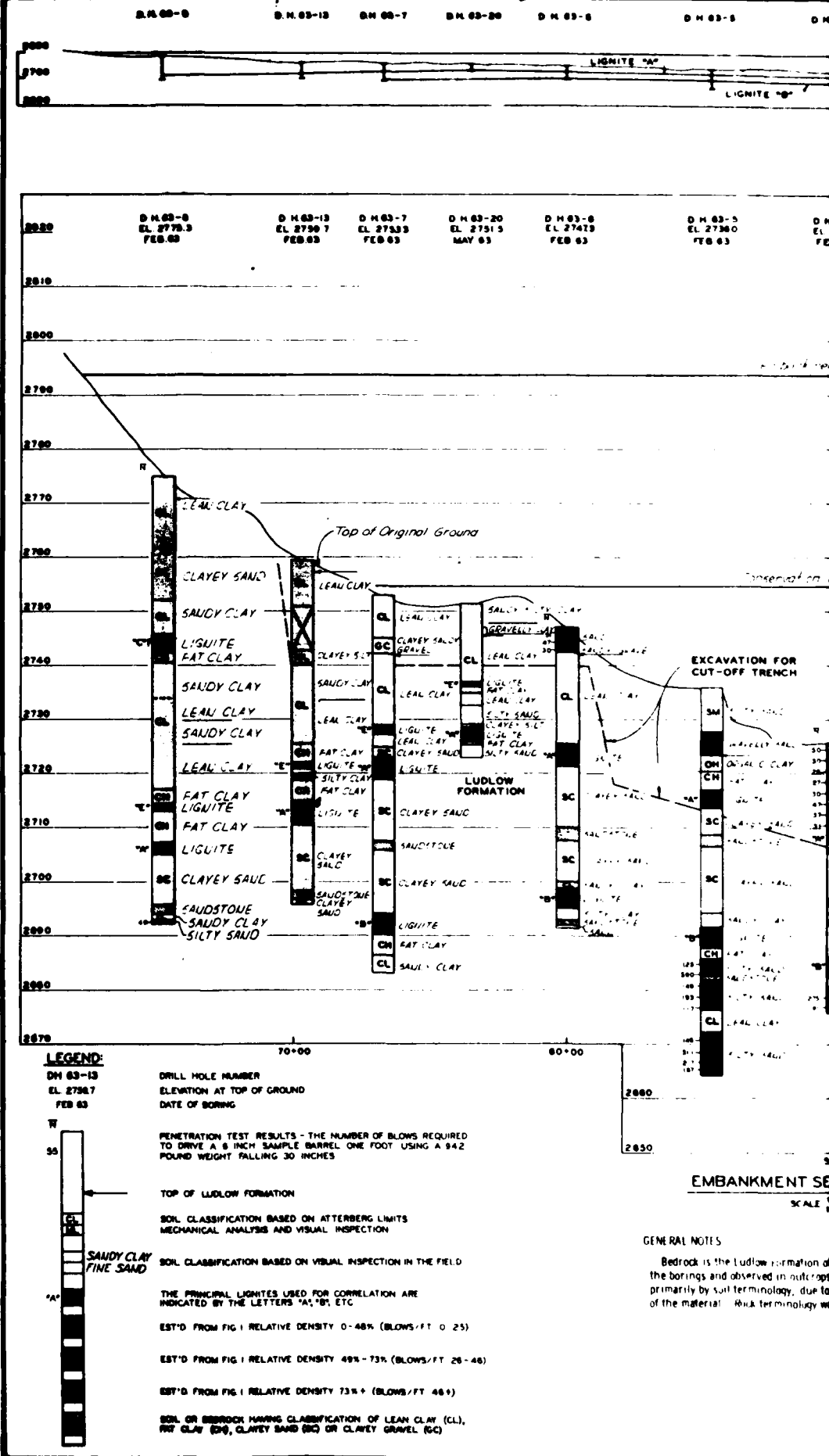
FIG. 1 - RELATIONS BETWEEN DRIVING RESISTANCE OF SAMPLER IN BLOWS PER FOOT AND RELATIVE DENSITY FOR GRANULAR SOILS
REF. BURMISTER, D.M. 1940 - "PRACTICAL METHODS FOR THE CLASSIFICATION OF SOILS," PURDUE (CMFE, P. 129)

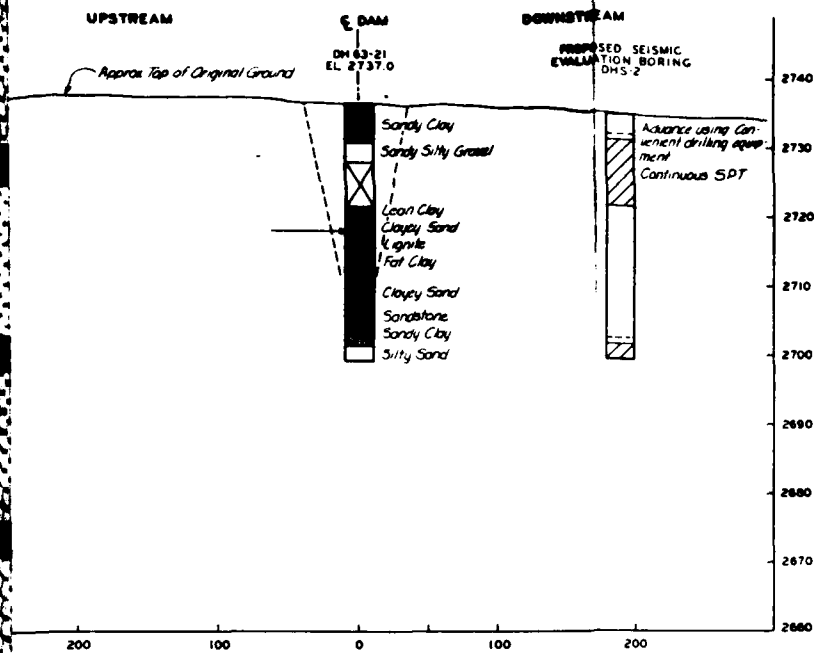
**NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS**

GEOLOGIC PROFILE ALONG EMBANKMENT C, SECTION 4-4

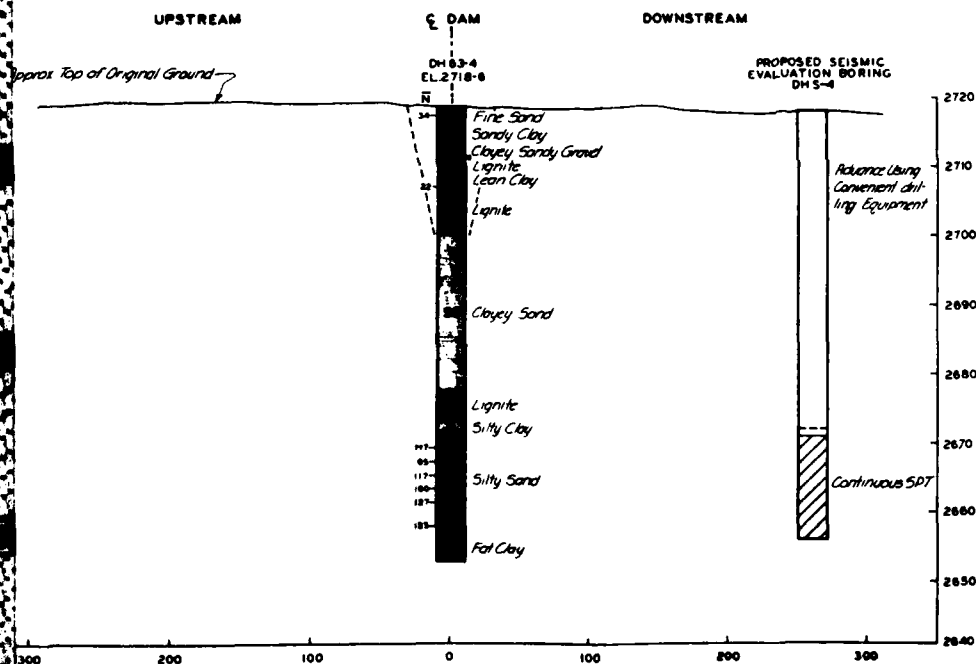
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

GROUP OF BORINGS



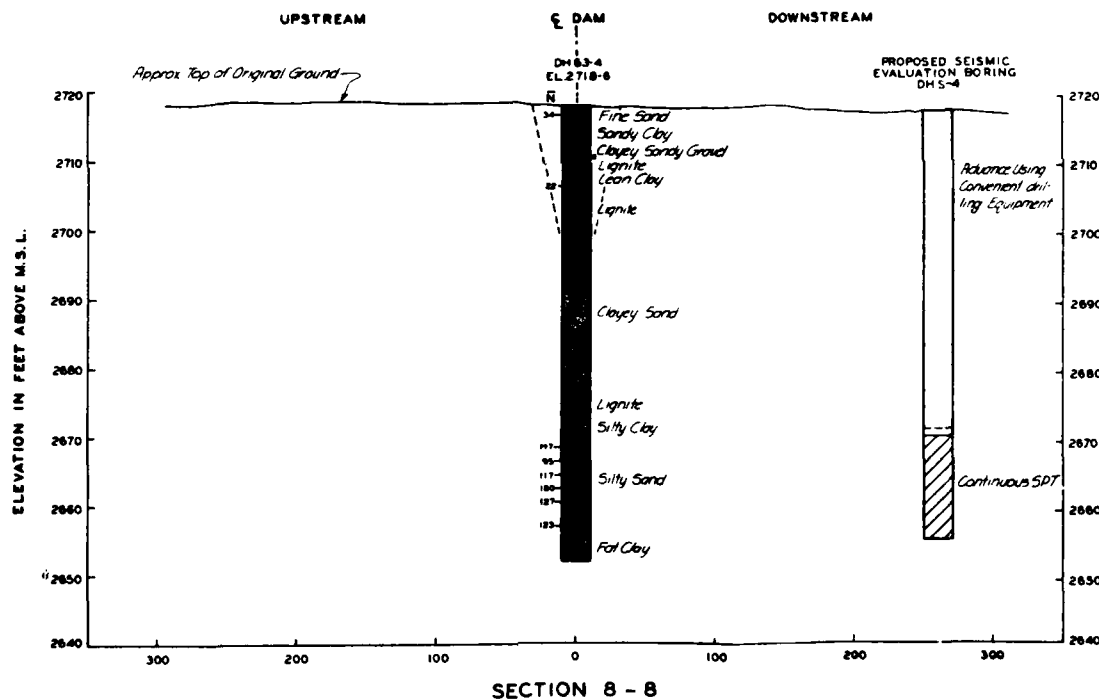
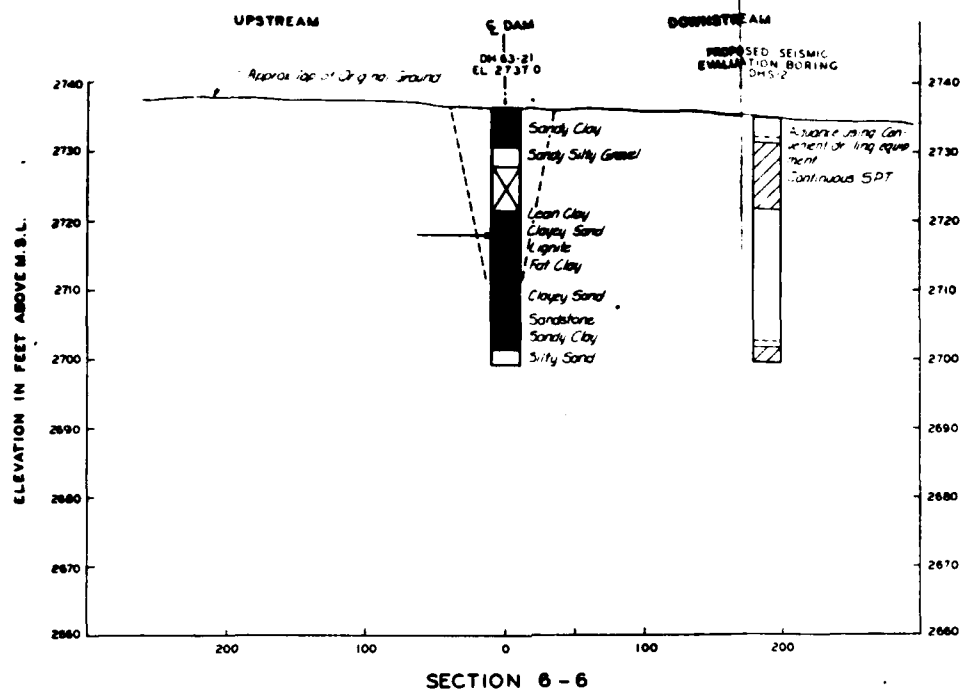


SECTION 8-6



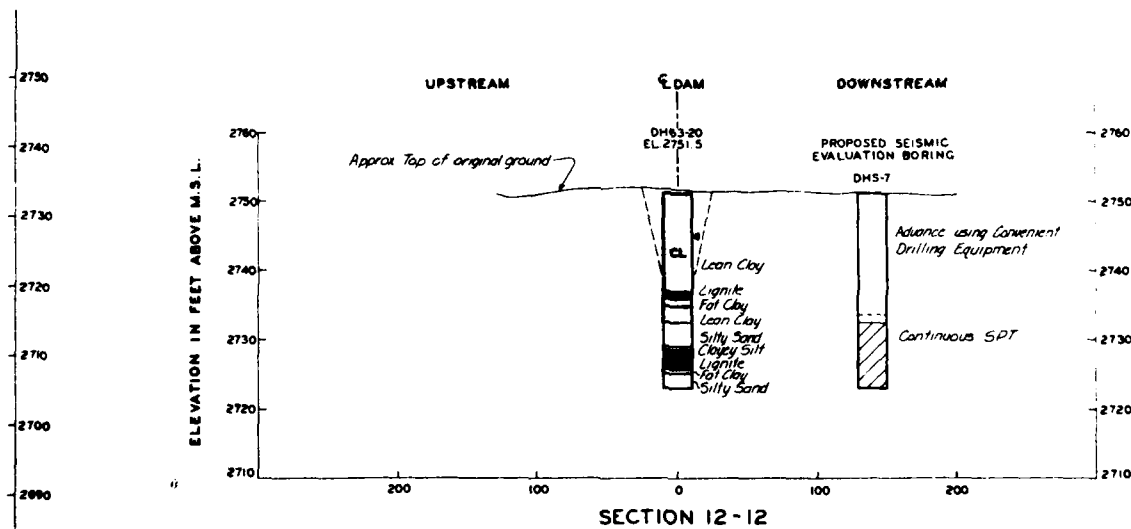
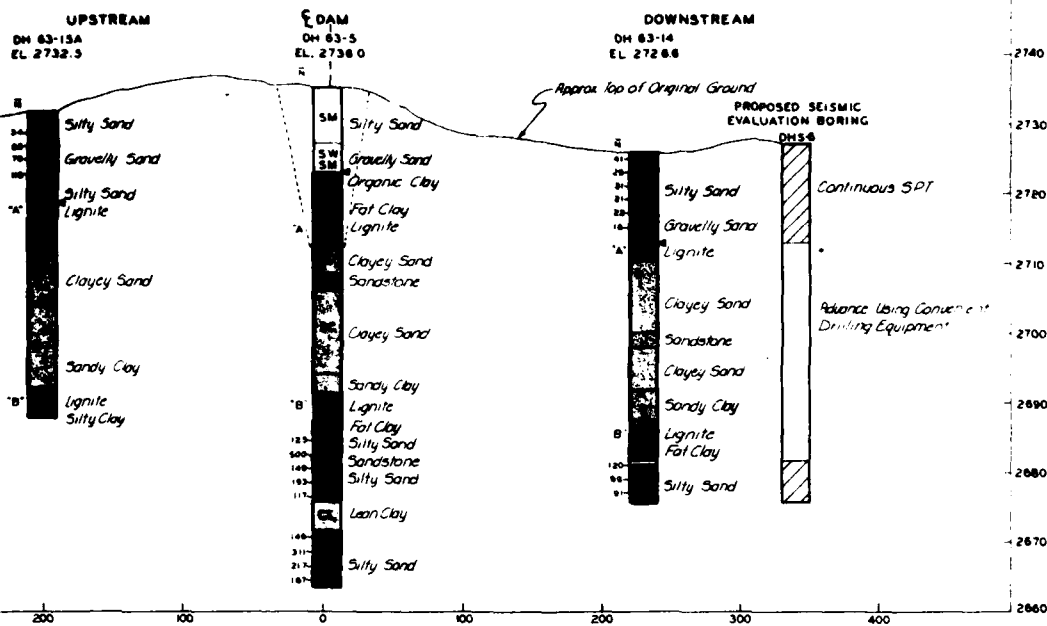
SECTION 8-8

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN - HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
GEOLOGIC SECTIONS 5-5 THRU 8-8 WITH ORIGINAL AND
PROPOSED SEISMIC EVALUATION FOUNDATION EXPLORATIONS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



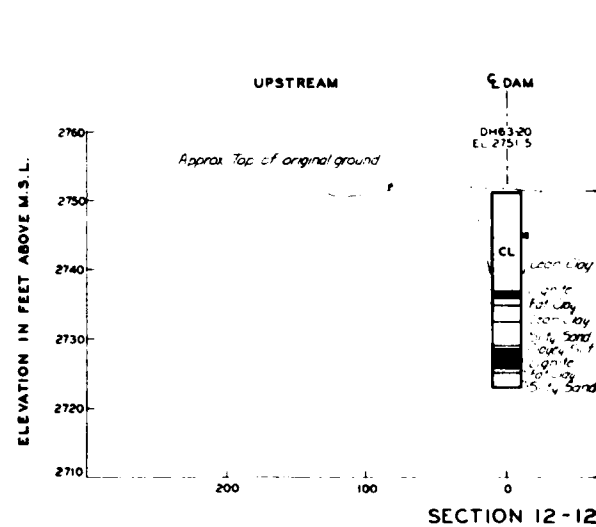
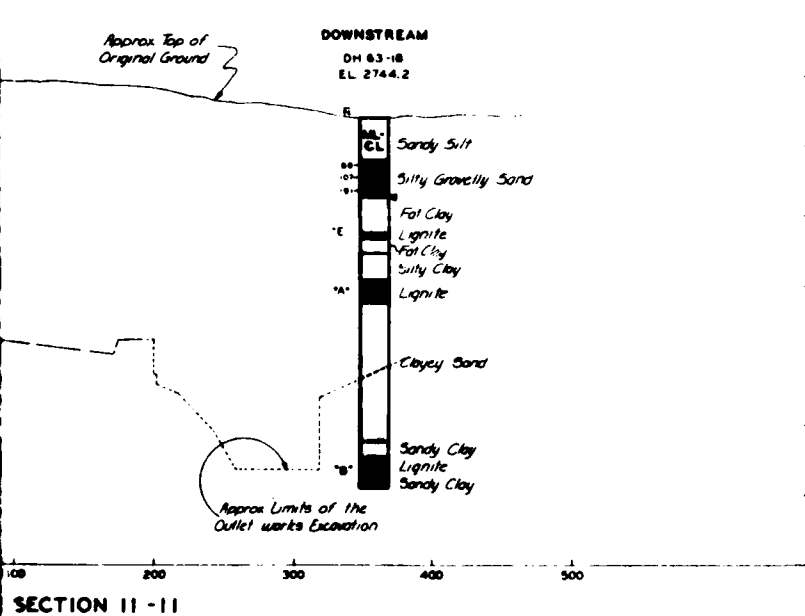
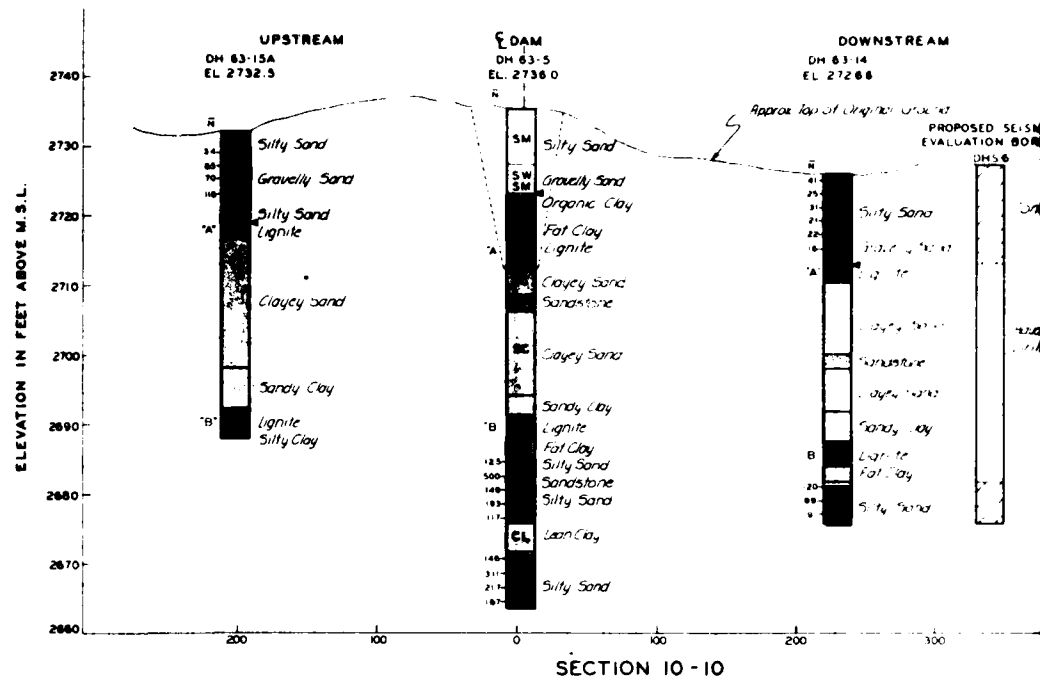
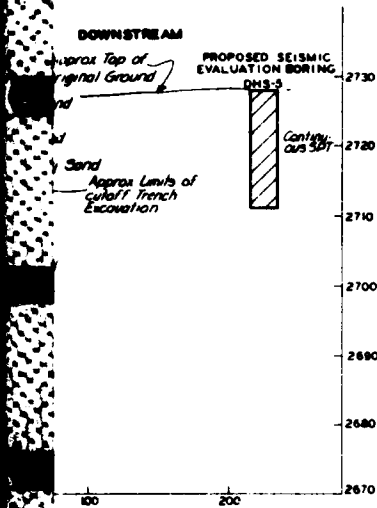
SCALE: VERT. 1 INCH = 10 FEET
HORIZ. 1 INCH = 50 FEET

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
GEOLOGIC SECTIONS 5-5 THRU 8-8 WITH ORIGINAL AND
PROPOSED SEISMIC EVALUATION FOUNDATION EXPLORATIONS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



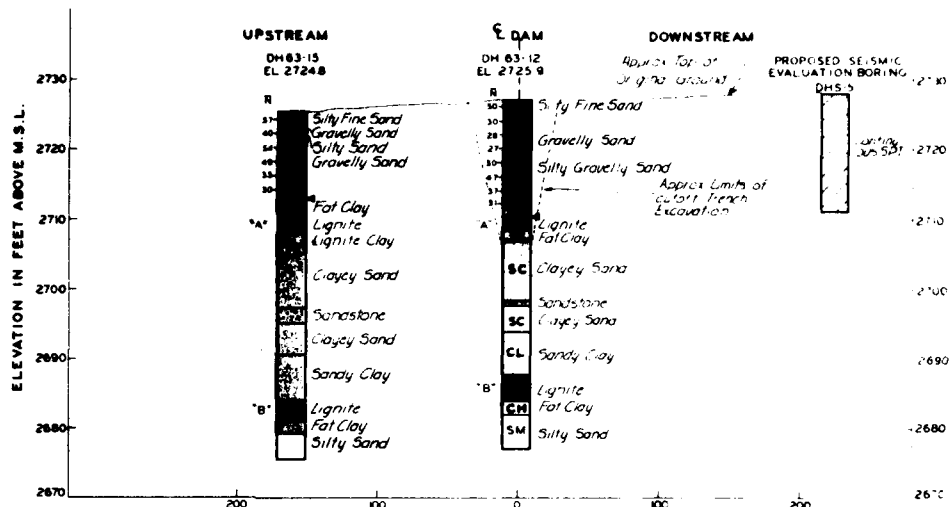
10 FEET
50 FEET

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
 BOWMAN - MALEY DAM AND LAKE
 RECONNAISSANCE REPORT
 SEISMIC EVALUATION AND ANALYSIS
 GEOLOGIC SECTIONS 8-8 THRU 12-12 WITH ORIGINAL AND
 PROPOSED SEISMIC EVALUATION FOUNDATION EXPLORATIONS
 U.S. ARMY ENGINEER DISTRICT, OMAHA
 CORPS OF ENGINEERS OMAHA, NEBRASKA

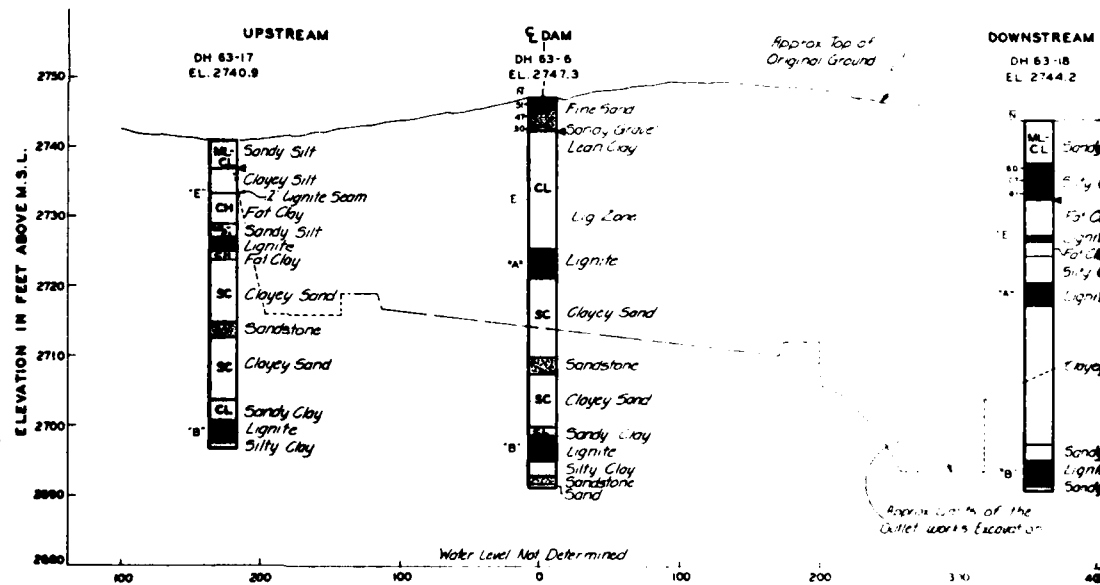


SCALE: VERT. 1 INCH = 10 FEET
HORIZ. 1 INCH = 50 FEET

NORTH
BOW
RECO
SEISMIC
GEOLOGIC SECTION
PROPOSED SEISMIC
U.S.
CORP.



SECTION 9 - 9



SECTION 11 - 11

APPENDIX A

PRELIMINARY SEISMIC HAZARD ANALYSIS

OMAHA DISTRICT	COMPUTATION SHEET	CORPS OF ENGINEERS
PROJECT: SEISMIC HAZARD ANALYSIS - BOWMAN-HALEY DAM SITE		
ITEM: CONVERSION OF CORNELL AND MERZ COEFFICIENTS FOR EASTERN U.S.	BY: BECKER	DATE
	CHKD. BY	DATE

ATTENUATION OF INTENSITY EQUATION FROM CORNELL AND
MERZ AS QUOTED IN NUTTLI AND GUPTA (1976)
UNITS OF DISTANCE ARE IN MILES, CONVERTING FOR
USE OF KILOMETERS

$$\begin{aligned}
 I_{SITE} &= 3.1 + I_{EPICENTER} - 1.3 \ln(R_{MILES}) \quad (1) \quad R_{MILE} = \frac{R_{KM}}{1.6} \\
 &= 3.1 + I_{EPICENTER} - 1.3 \ln(R_{KM}/1.6) \\
 &= 3.1 + I_{EPICENTER} - 1.3 [\ln(R_{KM}) - \ln(1.6)] \\
 &= 3.1 + I_{EPICENTER} + 1.3 \ln 1.6 - 1.3 \ln R_{KM} \\
 &= 3.1 + I_{EPICENTER} + .61 - 1.3 \ln R_{KM} \\
 I_{SITE} &= 3.71 + I_{EPICENTER} - 1.3 \ln R_{KM} \quad (2)
 \end{aligned}$$

USING NUTTLI AND HERRMANN'S RELATION FOR MAGNITUDE AND
EPICENTER INTENSITY (SEE 1978 WES MISC. PAPER 573-1
REPORT 12)

$$I_{EPICENTER} = 2.0 m_b - 3.5 \quad (3)$$

SUBSTITUTING THIS INTO (2)

$$\begin{aligned}
 I_{SITE} &= 3.71 + (2.0 m_b - 3.5) - 1.3 \ln R_{KM} \\
 I_{SITE} &= .21 + 2.0 m_b - 1.3 \ln R_{KM} \quad (4)
 \end{aligned}$$

FOR CORNELL'S (1968) EQUATIONS FOR INTENSITY

$$\begin{aligned}
 C_1 &= .21 \\
 C_2 &= 2.0 \\
 C_3 &= 1.3
 \end{aligned}$$

HERRMANN'S (1981) EQUATIONS FOR MAXIMUM ACCELERATION
FOR $R \leq 15 \text{ Km}$

USE LESSER OF: $\log_{10} a = 0.55 + 0.50 m_b - 0.83 \log_{10} 15 - 0.0019 (15)$
 $\ln_e a = 0.933 m_b$

FOR $R \geq 15 \text{ Km}$: $\log_{10} a = 0.55 + 0.50 m_b - 0.83 \log_{10} R - 0.0019 R$

OMAHA DISTRICT	COMPUTATION SHEET		CORPS OF ENGINEERS
PROJECT SEISMIC HAZARD ANALYSIS - BOWMAN-HALEY DAM SITE			
ITEM CORNELL'S (1968) EQUATIONS FOR CALCULATING	BY BELKER	DATE	
MAXIMUM INTENSITIES AT A SITE FROM A LINE SOURCE	CHKD. BY	DATE	

M_0 = MAXIMUM MAGNITUDE QUAKE ALONG SOURCE RECURRING IN 1000 YRS

Δ = DISTANCE (KM) FROM DAM TO CLOSEST POINT ON SOURCE

h = FOCAL DEPTH - ASSUMED TO BE 20 KM.

$d = \sqrt{\Delta^2 + h^2}$ = DISTANCE (KM) TO PT 20 KM BELOW CLOSEST PT ON SOURCE

Q = LENGTH OF SOURCE (KM)

$b = .92$ = SLOPE OF LINE RELATING CUM. ANN. FREQ. VS. MAGNITUDE

$B = b \ln 10 = 2.1$

$C_1 = .21$
 $C_2 = 2.0$
 $C_3 = 1.3$ } COEFFICIENTS FROM EQUATION RELATING INTENSITY TO MAGNITUDE
 SEE PAGE A3

N_{M_0} = RECURRENCE ANNUAL FREQ. FOR M_0 - CHOSEN AT .001

$Q/2$ = HALF LENGTH OF SOURCE

$r_0 = \sqrt{d^2 + \frac{Q^2}{4}}$ SEE DIAGRAM BELOW

$\hat{v} = \text{EVENTS/YR}/Q$ FREQUENCY OVER LENGTH OF SOURCE

$\gamma = \beta^2/C_2 - 1 = .37$ USED IN DETERMINING GEOMETRY FACTOR G

$C = e^{(B(C_1/C_2 + M_0))} = e^{(2.1(\frac{.21}{2} + M_0))}$

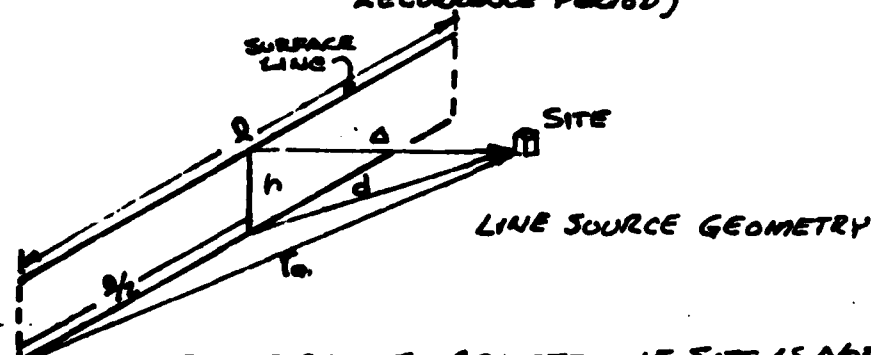
r_0/d = USED FOR DETERMINING T FUNCTION VALUE

$Q = \int_0^{\sec^{-1}(r_0/d)} \cos(u)^{\gamma-1} du$ READ FROM GRAPH (SEE NEXT PAGE)

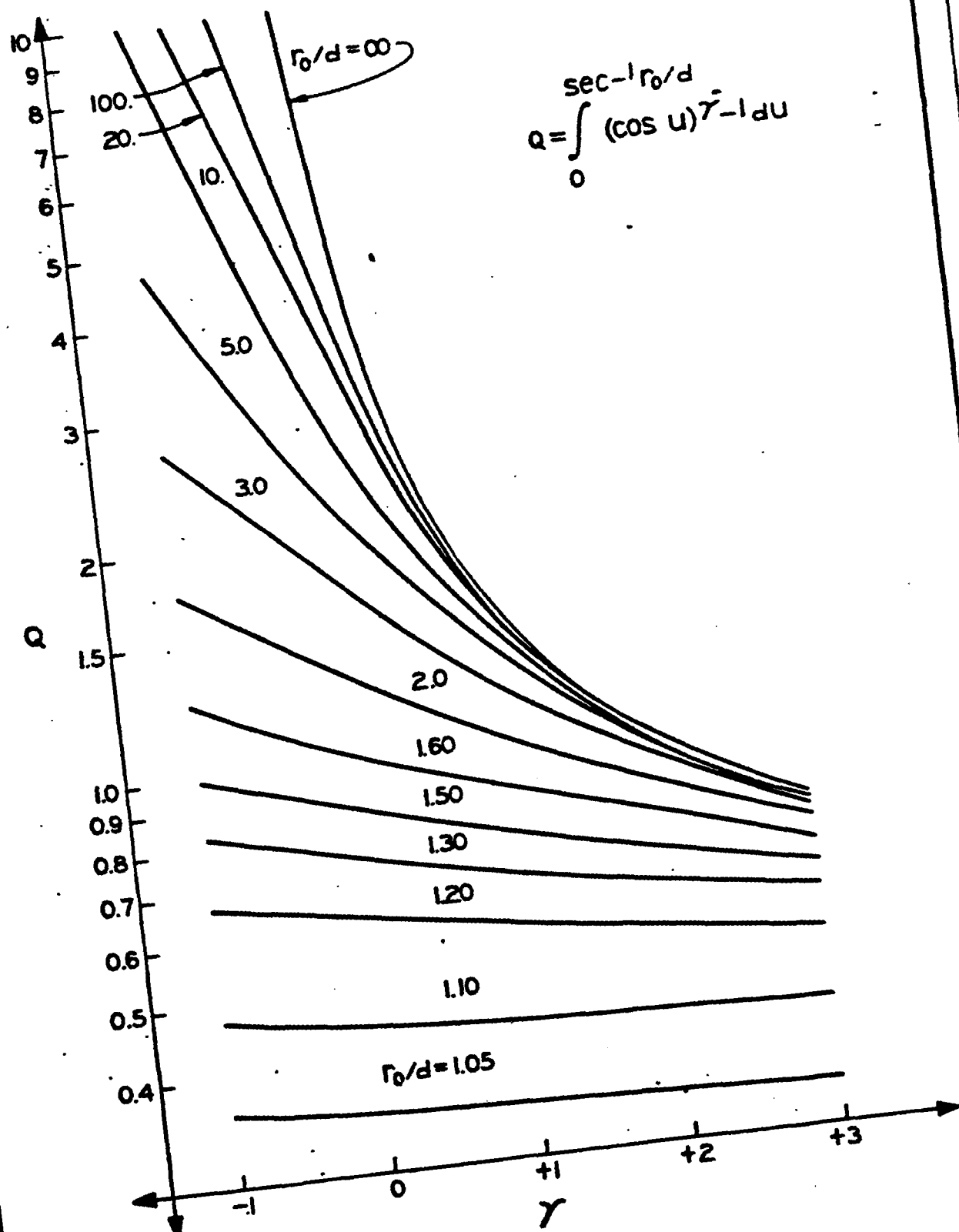
$G = (2/d^3) Q$ = GEOMETRY FACTOR FOR SOURCE

T_i = RECURRENCE PERIOD OF EARTHQUAKE OF INTEREST

$i = \frac{C_2}{B} \ln(\hat{v} C G T_i) = \text{MAX. INTENSITY AT SITE IN 1000 YRS}$
 GIVEN THAT MAX. MAGNITUDE OCCURRING
 ONCE IN 1000 YRS IS M_0 ($T_i = 1000$ YR
 RECURRENCE PERIOD)



GEOMETRY FACTOR CAN BE ADJUSTED IF SITE IS NOT CENTERED RELATIVE TO SOURCE BY TREATING EACH SIDE OF THE SOURCE AS HALF OR DIFFERENT LENGTH FAULTS, THEN MULTIPLYING THE RESPECTIVE G FACTORS BY $1/2$ AND SUMMING THEM. USING THE TOTAL G FACTOR, i CAN BE CALCULATED NORMALLY. A SIMILAR PROCESS CAN BE USED IF THE SOURCE LINE IS ENTIRELY SKEWED TO ONE SIDE; THE G FACTOR FOR THE 'MISSING' SEGMENT SUBTRACTED OFF.



SEISMIC EVALUATION
 NUMERICAL VALUES OF INTEGRAL USED IN
 CALCULATION OF GEOMETRY FACTOR
 U.S. ARMY ENGINEER DISTRICT, OMAHA
 GROUP OF ENGINEERS OMAHA, NEBRASKA
 FROM CORNELL (1968)

FIGURE A-3

PROJECT SEISMIC HAZARD ANALYSIS - BOWMAN - HALEY DAM SITE

ITEM CORNELL'S (1968) EQUATIONS FOR CALCULATING

BY BECKER

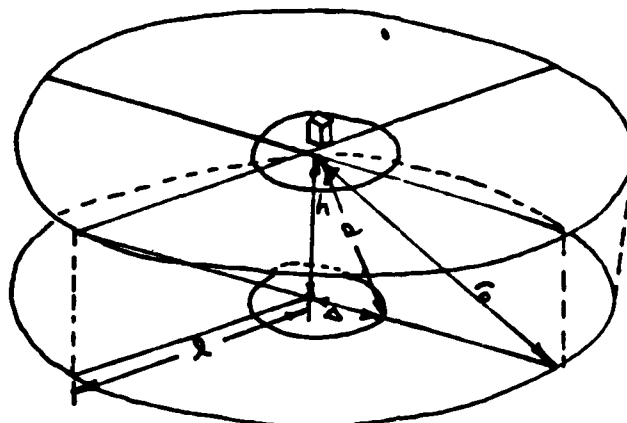
DATE

MAX. INTENSITIES AT A SITE FROM AN ANNULAR SOURCE

CHKD. BY

DATE

$m_0, h, b, B, N_{m0}, C_1, C_2, C_3, C, \gamma, i$ - ALL REPRESENT SAME QUANTITIES AS FOR LINE SOURCE, AND ARE CALCULATED THE SAME WAY.



ANNULAR SOURCE GEOMETRY

R = RADIUS OF OUTSIDE OF ANNULUS

Δ = RADIUS OF INSIDE OF ANNULUS (CAN BE ZERO)

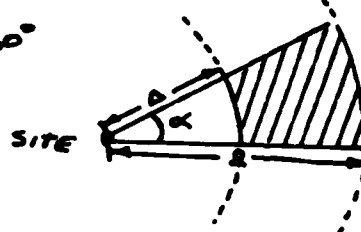
$$d = \sqrt{h^2 + \Delta^2}$$

$$r_0 = \sqrt{h^2 + R^2}$$

$$\hat{v} = N_{m0} / \text{AREA} = N_{m0} / \pi (R^2 - \Delta^2) \text{ EVENTS PER YEAR PER UNIT AREA (km}^2\text{)}$$

$$G = \frac{2\pi}{(\gamma-1)d^{(\gamma-1)}} \left[1 - \left(\frac{r_0}{d} \right)^{(\gamma-1)} \right] \text{ GEOMETRY FACTOR}$$

GEOMETRY FACTOR CAN BE ADJUSTED FOR ONLY A SEGMENT OF AN ANNULUS BY MULTIPLYING G BY THE PORTION OF THE ANNULUS THAT THE SEGMENT SUBTENDS - $\alpha/360^\circ$



$$G_{\text{segment}} = \frac{\alpha}{360^\circ} G_{\text{annulus}}$$

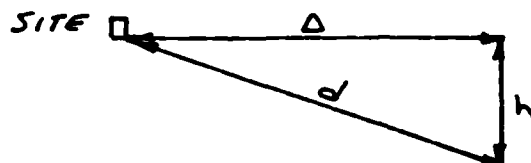
α IN DEGREES

G FACTORS CAN BE SUMMED FOR SEVERAL ANNULAR SEGMENTS USED TO MODEL AN IRREGULAR AREAL

SOURCE - $\hat{v} G_{\text{TOT}} = \hat{v} \sum_{i=1}^n G_i$

OMAHA DISTRICT		COMPUTATION SHEET		CORPS OF ENGINEERS	
PROJECT SEISMIC HAZARD ANALYSIS - BOWMAN-HALEY DAM SITE					
ITEM CORNELL'S (1968) EQUATIONS FOR CALCULATING				BY BECKER	DATE
MAX. INTENSITIES AT A SITE FROM A BLT SOURCE				CHKD. BY	DATE

$m_0, h, b, B, N_{m0}, C_1, C_2, C_3, C, \gamma, L$ - ALL REPRESENT SAME QUANTITIES AS FOR LINE SOURCE, AND ARE CALCULATED THE SAME WAY.



Δ - DISTANCE TO PT. SOURCE FROM SITE (ALONG SURFACE)

$d = \sqrt{\Delta^2 + h^2}$ - DISTANCE TO FOCUS FROM SITE

$$G = d^{-(\gamma+1)}$$

Williston Basin Axis

1872-1983

CUMULATIVE ANNUAL
FREQUENCY VS. MAGNITUDE

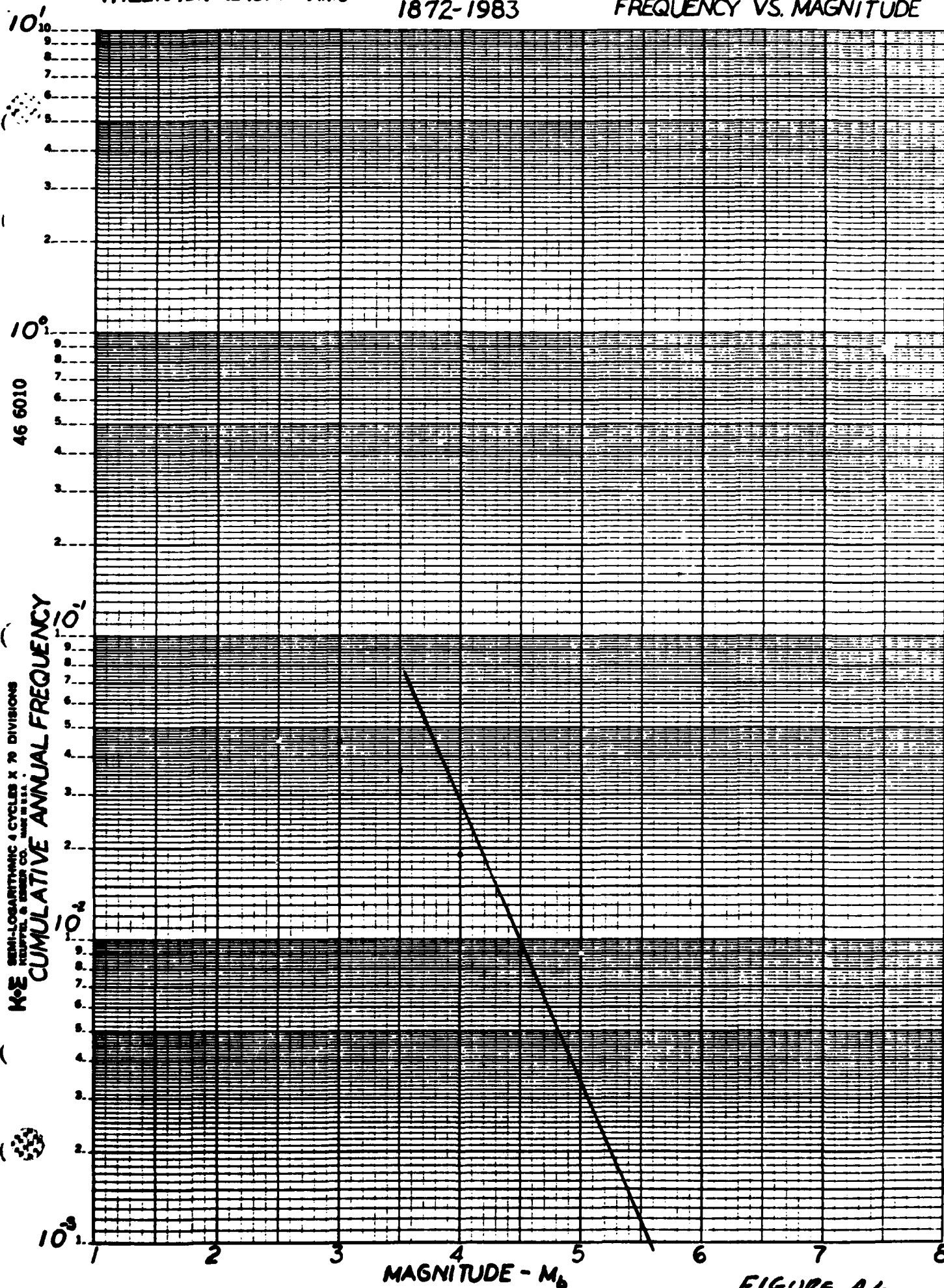


FIGURE A1-

INPUT SITE NAME
 ? BOWMAN HALEY DAM
 INPUT SOURCE NAME
 ? WILLISTON BASIN AXIS
 ENTER DEPTH TO FOCUS, ACTUAL LENGTH OF SOURCE AND MO
 ALL DISTANCES IN KILOMETERS
 ? 5.631,5.5,6
 IS THE SOURCE SYMMETRIC ABOUT THE SITE?
 TYPE Y OR N.
 ? N
 CAN A LINE NORMAL TO THE SOURCE BE DRAWN
 FROM THE CLOSEST PT ON THE SOURCE TO THE SITE?
 TYPE Y OR N
 ? Y
 THE SOURCE WILL BE CONSIDERED AS 2 SEGMENT FAULTS
 OF DIFFERENT LENGTHS. PLEASE ENTER DISTANCE FROM
 SITE TO SOURCE.
 ? 27.5

 ENTER LENGTH OF SEGMENT 1
 ? 314.5

 ENTER LENGTH OF SEGMENT 2
 ? 317.0

 C1 = .21
 C2 = 2.00
 C3 = 1.30

 B = .92
 BETA = B(LN10) = 2.10
 NMO = .001

 T = 1000.0
 C = 159611.82

 V = .001/ACTUAL SOURCE LENGTH = .158E-05

 GEOMETRY FACTOR = .133E+01

 (SUM OF GEOMETRY FACTOR)(V) = .211E-05

 I = (C2/BETA) LN((BV)(C)(T)) = 5.54

 MB = (I+3.5)/2 = 4.52

 LOG A = .55 + .5(MB) - .18(LN15) - .0019(15) = .181E+01

 A = 63.973

 ACCELERATION = .065 G

 OR

 LN A = .933(MB) = 4.218

 A = 67.923
 ACCELERATION = .069 G

END ANALYSIS OF BOWMAN HALEY DAM
 SOURCE AREA -- WILLISTON BASIN AXIS

APPENDIX B

**DETAILED DESCRIPTIONS
EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES**

APPENDIX B

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u> <u>MMI 1/</u>	<u>Description 2/</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>(Est'd Mag., M_b)</u>	
09 February 1872	Ft. Sully, SD 44°36'	100°46'	III (3.4)	The local earthquake was felt.
17 August 1876	Lower Brule Indian Reservation, SD 44°06'	99°36'	IV (3.8)	The shock lasted 7 seconds. Loud rumbling noises were heard.
15 April 1878	Glendive, MT 47°08'	104°41'	IV (3.8)	Three shocks at half hour intervals rent the ground for 500 yds. at Glendive, MT.
25 June 1894	Casper, WY 42°54'	106°18'	V (4.3)	Dishes fell to the floor. A number of people were thrown from their beds. The Platte River became thick with mud.
11 October 1895	Black Hills, SD 43°54'	103°18'	V (4.2)	The shock was felt at Rochford, Keystone, and Hill City, SD. Two aftershocks rocked houses and rattled dishes.
14 November 1897	Casper, WY 42°54'	106°18'	VII (5.0)	The Grand Central Hotel was damaged considerably, with 2 to 4 inch crack extending from third to first story. Frightened citizens dashed into the streets.

1/ Modified from Barstow, N.L., et al. "An Approach to Seismic Zonation for Siting Nuclear Electric Power Generating Facilities in the Eastern United States," U.S. Nuclear Regulatory Commission, NUREG/CR-1577, 1981.

2/ Modified from Docekal, J., 1970, Earthquakes of the Stable Interior, with Emphasis on the Midcontinent, v. 2, A dissertation presented the faculty of the graduate college in the University of Nebraska in partial fulfillment of requirements for the degree of Doctor of Philosophy, Ann Arbor, Michigan, University Microfilms Ltd., p. 1-332.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u> <u>MMI 1/</u>	<u>Description 2/</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>(Est'd Mag., m_b)</u>	
14 March 1900	Aberdeen, SD 45°28'	98°28'	III-IV (3.6)	Two slight earthquakes were felt.
09 May 1906	South Dakota- Nebraska Border 43°00'	101°18'	VI (4.7)	The shock was felt in Rushville and Valentine, NE.
08 August 1915	Williston, ND 48°09'	103°38'	IV (3.8)	A shock was felt lasting 2 to 5 seconds which awakened residents, shook houses, and rattled dishes.
23 October 1915	Kadoka, SD 43°48'	101°30'	V (4.2)	The earthquake was felt.
24 February 1916	Pine Ridge, SD 43°00'	102°30'	III (3.4)	Two moderate shocks lasting a total of 45 seconds were felt.
14 July 1920	Oelrichs, SD 43°10'	103°13'	III (3.7)	A shock with no noise was reported as lasting a few seconds. The shock was also felt at Hot Springs, SD, where rumbling was heard.
30 December 1924	Hot Springs, SD 43°28'	103°32'	IV (3.8)	Several shocks occurred over a 20-minute period and were felt by many persons. The disturbance consisted of abrupt rocking accompanied by rumbling. At Rapid City, the ground vibrated in a north-south direction.
17 November 1925	Bighorn, WY 44°40'	107°00'	V (4.3)	An earthquake felt by many. It lasted 1.5 to 2.0 minutes. Rumbling was heard in the mountains and the ground trembled in a northeasterly-southeasterly direction. Affected to a lesser extent were: Buffalo, Dome Lake, Ft. McKenzie, and Sheridan, WY.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u>	<u>Description ^{2/}</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>MMI ^{1/}</u> <u>(Est'd Mag., m_b)</u>	
01 May 1926	Osage, WY 43°59'	104°24'	IV (3.8)	The earthquake was distinctly felt. Objects moved and dishes shifted.
29 April 1927	Hebron, ND 45°54'	102°04'	III (3.4)	A trembling and rocking in an east-west direction was felt. Pictures moved, hanging objects swung.
13 February 1928	Near Thermopolis, WY 43°30'	108°12'	V (4.3)	Mine props loosened during the earthquake and later became tight.
16 November 1928	Black Hills, SD 44°07'	103°44'	V (4.2)	The shock was felt at Custer and Rockford, SD. Rocks fell on tracks and doors swung open.
10 January 1932	Colstrip, MT 45°54'	106°38'	IV (3.8)	Two severe shocks were felt. The first and strongest sounded like a muffled dynamite blast and shook a huge power shovel until its cables whipped.
29 January 1934	Newark, SD 45°54'	97°44'	IV (4.2)	The shock awakened several persons and rattled dishes.
16 October 1935	Chinook, MT 48°36'	109°14'	III (3.0)	A slight earthquake was reported.
30 October 1936	Hot Springs, SD 43°28'	103°32'	IV (3.8)	The tremor rattled dishes.
25 May 1941	Hot Springs, SD 43°28'	103°32'	IV-V (4.0)	The shock was also felt at Rapid City and Martin, SD. One wall cracked and hanging objects swayed.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u>	<u>Description ^{2/}</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>MMI ^{1/}</u> <u>(Est'd Mag., M_b)</u>	
11 March 1942	Sturgis, SD 44°25'	103°31'	III-IV (3.6)	Distinct tremors were felt in a narrow strip in the northern Black Hills. Reports were received from Black Hawk, Lead, Fort Meade, Sturgis, Englemwood, Trojan, Nevada Gulch, and Terra-ville. Rapid City reported that rumbling occurred and that the shaking lasted for 12 seconds.
11 December 1942	Casper-Columbine, WY 43°11'	106°18'		Many people were awakened by a sharp shock. Dishes rattled. It was also felt strongly at Edgerton and Glenrock, WY.
16 May 1943	Hot Springs, SD 43°28'	103°32'	IV (3.8)	Dishes rattled for 5 seconds at Hot Springs, SD, and southward for several miles.
24 June 1943	Homestead-Froid, MT 48°24'	104°30'	VI (4.8)	A strong shock was felt. Subterranean sounds were heard, basement walls cracked and a granary cracked severely.
06 September 1943	Buffalo, WY 44°21'	106°42'	IV (3.8)	A shock caused houses to creak and windows to rattle. Many people felt a swaying motion.
26 October 1946	Williston, ND 48°09'	103°38'	IV (3.8)	A slight shock lasting 5 seconds rattled dishes and was felt by many persons. Plentywood, MT, reported a very slight shock at the same time.
14 May 1947	Selfridge, ND 46°02'	100°57'	IV (3.8)	The shock was felt in the Missouri River Valley and possibly from Beulah, ND, to Pierre, SD.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u> <u>MMI 1/</u>	<u>Description 2/</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>(Est'd Mag., m_b)</u>	
16 May 1947	Pierre, SD 44°24'	100°18'	III-IV (3.6)	Pierre reported a slight shock lasting 2 seconds. A few persons felt the shock which rattled dishes.
27 August 1948	Casper, WY 42°51'	106°18'	IV (3.8)	An earthquake of a few seconds duration rattled loose objects. Buildings creaked.
03 June 1949	North Central South Dakota 45°00'	100°00'	IV (3.8)	The shock was felt in South Dakota and Nebraska.
15 November 1952	Pactola, SD 44°05'	103°31'	IV (3.8)	The sharp tremor startled people during the night.
21 December 1953	Zeona, SD 45°12'	102°54'	III-IV (3.6)	The earthquake caused a table to jump and rattle. A single observer made the report.
02 December 1956	Vandalia, MT 48°21'	106°52'	IV (3.8)	The shock stampeded cattle.
31 December 1961	Pierre, SD 44°24'	100°30'	V-VI (4.5)	Plaster cracked, a cement floor cracked, a clothes dryer moved several inches, and hundreds of fish leaped into the air along the Missouri River. Many people were alarmed.
24 March 1964	Hot Springs, SD 43°28'	103°32'	V (4.2)	The shock, lasting 3 to 5 seconds, was felt by many persons. Small rocks fell in Wind Cave. Small objects and windows rattled. Moderate rumbling noises were heard.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u> <u>MMI 1/</u>	<u>Description 2/</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>(Est'd Mag., m_b)</u>	
28 March 1964	Merriman, NE 42°54'	101°36'	VII (5.1)*	Dishes were shaken from tables, canned goods fell from shelves, cracks appeared in the road, and the banks of the Niobrara River slumped. Four shocks were felt 4 minutes apart. The shocks originated from the northwest and were accompanied by thunder-like noises. A number of towns reported slight damage consisting chiefly of cracked or fallen plaster and broken dishes. The depth of focus was about 41 km. The felt area was estimated to be 90,000 square miles.
26 August 1964	South Dakota 43°48'	102°12'	IV (4.4)*	The shock was recorded with a focal depth of 15 km.
21 August 1964	Keeline, WY 42°54'	104°42'	V (4.3)	The moderately strong shock was also felt inusk, Lost Springs, Lance Creek, Jay Em, and Rode, WY.
21 August 1964	Keeline, WY 42°54'	104°42'	II (3.0)	A mild aftershock was felt.
26 June 1966	Keystone, SD 44°18'	103°43'	VI (4.1)*	The shock made well water muddy. One observer reported that he saw the ground move, buildings creak, and dishes rattle. At Rapid City, concrete steps cracked and pulled

* Magnitude was instrumentally determined.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

<u>Date</u>	<u>Locality</u>		<u>Intensity,</u> <u>MMI 1/</u>	<u>Description 2/</u>
	<u>Lat. N.</u>	<u>Long. W.</u>	<u>(Est'd Mag., m_b)</u>	
26 June 1966 (Cont'd)				away from houses, and various objects were shaken from walls. Moderately loud earth noises were heard.
08 July 1968	South Central North Dakota 46°30'	100°36'	IV (4.4)	A description is not available.
19 October 1971	South Dakota 44°00'	101°00'	IV (3.0)	The shock occurred between Philip and Pierre, SD. A description is not available.
16 May 1975	Edgemont, SD 43°14'	103°41'	IV (2.9)*	A description is not available.
25 August 1975	Pierre, SD 44°15'	100°27'	-- (3.1)*	A description is not available.
13 September 1981	Nebraska-South Dakota Border 43°00'	101°48'	IV (3.4)*	The shock was felt at Martin and Vetel, South Dakota.
03 March 1983	Stephan, SD 44°12'	99°18'	V (4.4)*	The shock was centered near Stephan, South Dakota. Minor damage was done to two nearby Indian reservations. The earthquake was felt from Sioux Falls to Pierre, South Dakota.

END

FILMED

8

D.M.C.